SEDIMENTOLOGY OF THE MURREE FORMATION (RAWALPINDI GROUP) IN KOHAT-POTWAR AREA.

M.Phil Thesis

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ABSTRACT

Strata of the Murree Formation, which consists of clay, siltstone, sandstone and conglomerate, were studied in detail at three localities; namely Dhok Maiki the stratotype in the Potwar area, Ghorzai and at Pathan Algad. The latter two localities are the principal reference sections in the Kohat Basin.

At Dhok Maiki the Murree Formation unconformably overlies the Eocene Chorgali Formation and consists of 5 major sand-bodies which range in thickness from 4m to 62m. The basal sand-body DM1 is 62m thick with a prominent conglomerate unit at the base consisting of reworked limestone clasts from the Chorgali Formation. These conglomerate beds become more laterally extensive and pass upward into sandstone suggesting the widening and stabilization of the channel with time.

At Ghorzai the formation consists of 45 percent of sandstone with subordinate conglomerate and 55 percent of clay. The sand-bodies are thin in size in the lower levels and get thicker in the middle and upper levels.

At Pathan Algad the Murree Formation consists of two prominent sand-bodies; one in the lower level and other in the middle level. Rest of the section either consists of interbedded sandstone and

clay facies or only clay facies.

Internally, the sandstone displays a variety of features such as megaripples, small scale climbing ripples, trough cross-bedding, horizontal lamination and are massive. These sand- bodies consist of main channel, point bar, and chute bar deposits. Interbedded sandstone and clay facies which overlie the composite sandstone facies represent crevasse splay or levee deposits. The red clay was deposited in flood plain areas out of suspension. The paleochannel analysis suggest that these sediments were deposited as a result of bed-load, mixed-load, and by suspension-load mechanisms.

The following lithofacies have been identified in the field. Lithofacies (Gmt) Trough cross-bedded/massive conglomerate, Lithofacies (Gtp) Trough/planar cross-bedded sandstone, Lithofacies (Shl) Low angle to plane-bedded sandstone, Lithofacies (Sr) Rippled sandstone, Lithofacies (Fl) Interbedded sandstone and clay facies, and Lithofacies (Fc) Massive red clays.

Comparison of the Murree Formation at three studied localities suggest that the Dhok Maiki area marks the initiation of the Murree river system. On the other hand the Pathan Algad area laid at the western margin where only occasionally the main river flowed. The Ghorzai area lied within the two extreme margins of the main Murree river system. Additionally there may be a considerable age difference between the exposures in southern Kohat and that of Dhok Maiki in Potwar area.

The provenance studies of the sandstone of Murree Formation suggest the supply of material from the orogenic belts to the north. Majority of the samples suggest recycled orogen provenance either from collision orogen or foreland uplift sources or combination of both.

TABLE OF CONTENTS

CHAPTER 2

SEDIMENTOLOGY OF THE SECTIONS

CHAPTER 3

LITHOFACIES OF THE MURREE FORMATION

LIST OF TABLES

LIST OF FIGURES

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CHAPTER 1

INTRODUCTION

This study deals with the Murree Formation which is the basal unit (Tab. 1.1) of the Rawalpindi Group (Shah, 1977).

Rocks of the Rawalpindi Group form part of the sub-Himalaya and are distributed along the southern margin of the main Himalayan ranges which are cut off in the north by the Main Boundary Thrust. These rocks are scattered up to northern Indian Plain, coming to the south these rocks enter Jammu to Hazara- Kashmir Syntaxis, and from there these rocks extend towards the Salt Range and thin out in southwest of Kohat (Fig. 1) (Bossart and Ottiger,1989).

The Murree Formation is composed of clay, sandstone, siltstone and conglomerate. Sandstone is maroon purple and grayish in color and dominantly medium-grained. Clay is reddish, brownish and purple in color. Basal conglomeratic unit of the formation at stratotype has been designated as Fatehjang member (Shah, 1977). It consists of reworked fossils from the underlying Eocene formations, plant remains, animal remains, and pieces of silicified wood. The formation is well exposed in the eastern Kohat, northern Potwar and in the Hazara-Kashmir syntaxis. Its thickness generally increases northward. The formation is diachronous; 40ma old in Hazara-Kashmir Syntaxis (Bossart and Ottiger, 1989), and 18-26ma old in Kohat-

Potwar area (Shah, 1977). The overlying Kamlial Formation consists of purple grey and maroon sandstone which is hard and medium-grained. Interbeds of hard purple shale and lenses of intraformational conglomerate of yellow and purple color occur at different intervals (Fatmi, 1973).

Strata of the Murree Formation are the early molasse deposits of the Himalayan foreland basin. The foreland basin is characterized by the southward migrating depositional basin in response to the deformation of the orogenic belt (Raynold and Johnson, 1985). These sediments in the Kohat Potwar Plateau are exposed in an approximately 100 Km wide foreland fold-thrust belt (Fig. 2).

Paleocene-Eocene deposits are separated from Paleozoic and Mesozoic marine shelf sediments below by a major regional unconformity and are separated from younger Himalayan molasse (Rawalpindi Group and Siwalik Group) by a regional paraconformity that represents non-deposition with little erosion and no folding during late Eocene and Oligocene times (Wells, 1984).

Epoch	Group	Formation	
PLIOCENE	SIWALIK GROUP	SOAN FORMATION	
		DHOK PATHAN FORMATION	
MIOCENE		NAGRI FORMATION	
		CHINGI FORMATION	
	RAWALPINDI GROUP	KAMLIAL FORMATION	
		MURREE FORMATION	
OLIGOCENE		UNCONFIRMITY	
EOCENE		KOHAT FORMATION	
		KULDANA FORMATION	
		JATTA GYPSUM	CHASHMAI AND SHEKHAN FORMATIONS
		BAHADUR KHEL SALT	
		PANOBA FORMATION	

Table 1.1 Stratigraphy of the Eocene and younger strata in the Kohat Basin (after Ahmed, 1989; Tanoli et al., 1992; Tanoli et al., 1993).

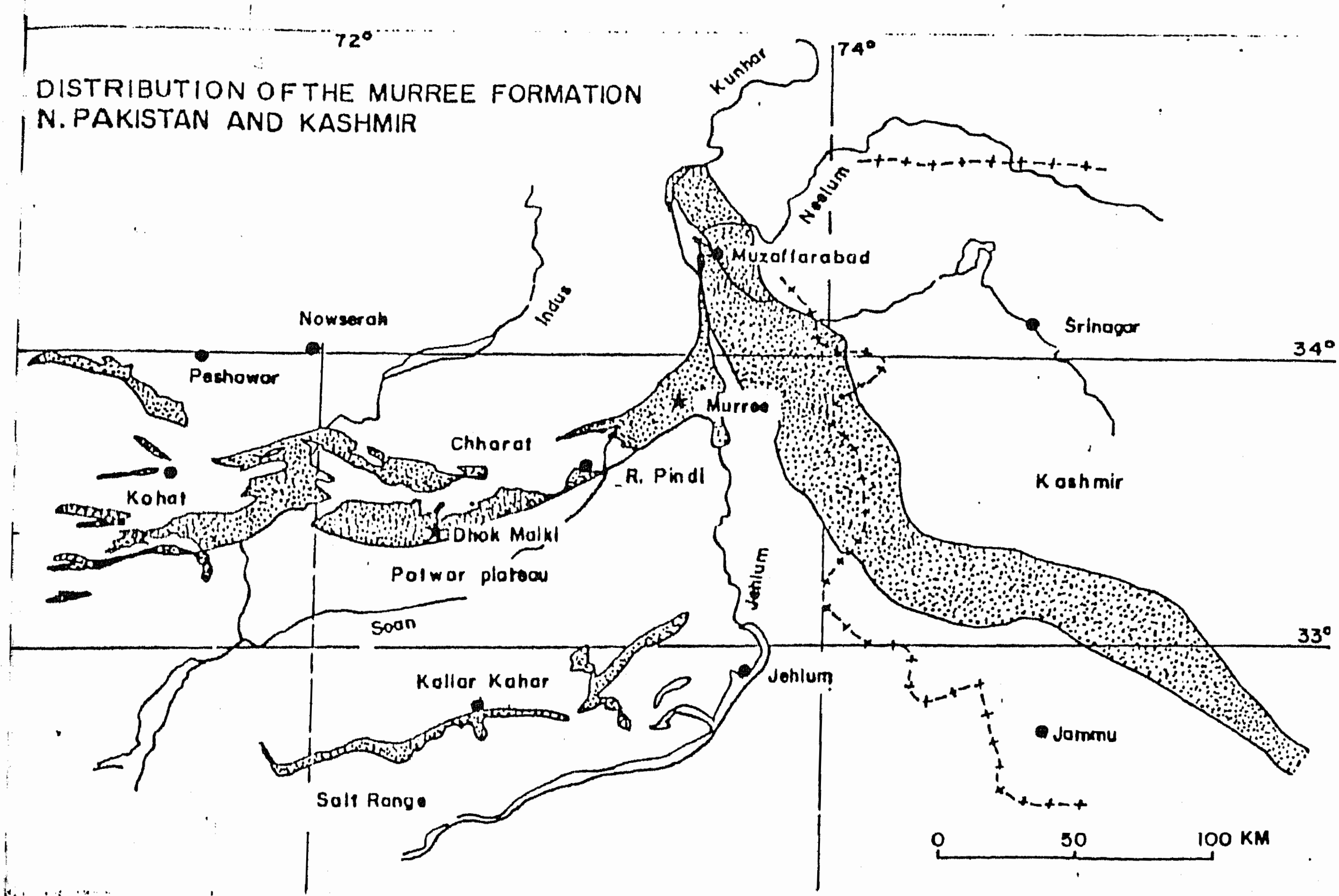
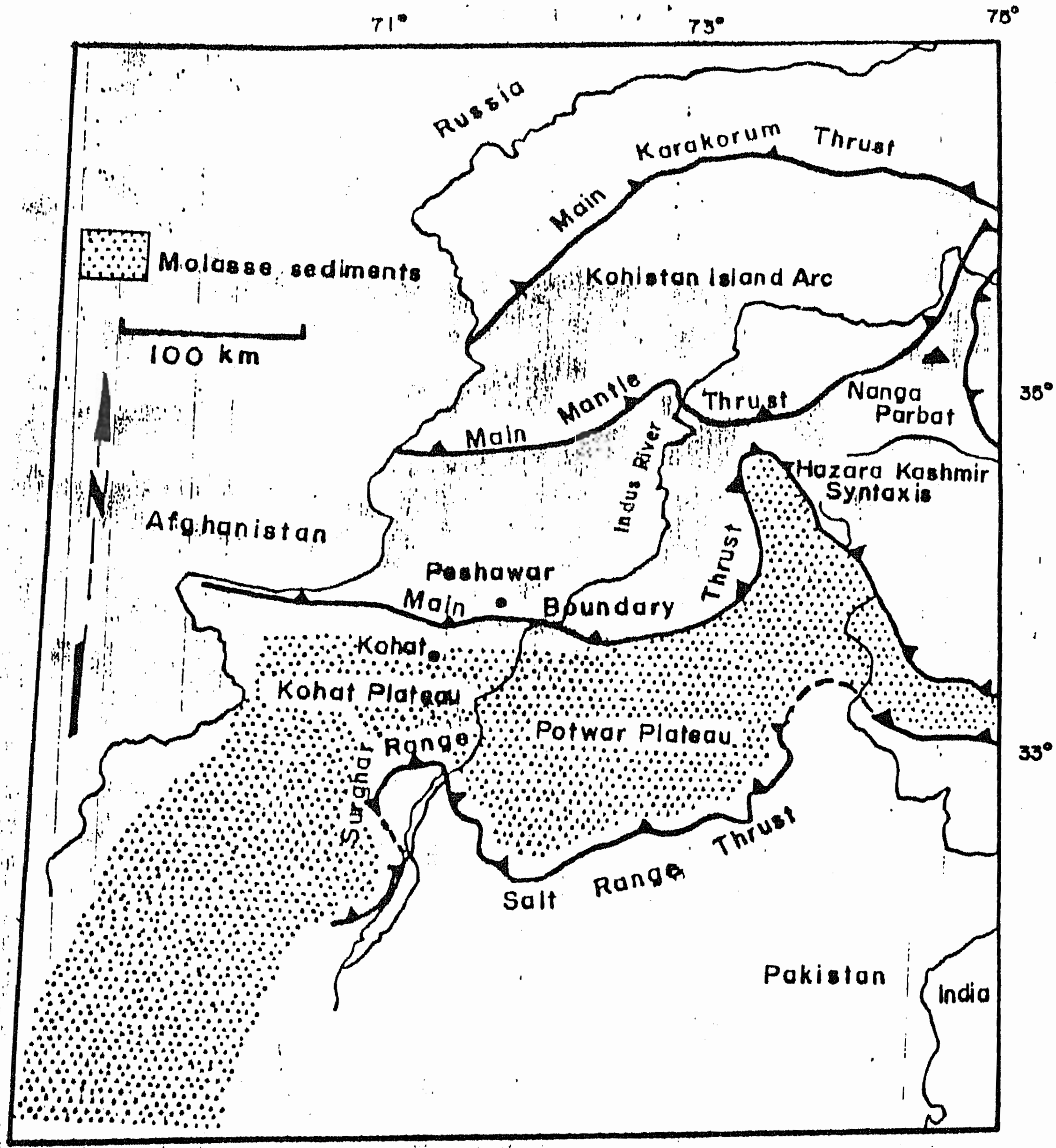


Fig 1 Distribution of the Murree Formation in northern Pakistan (after Bossart and Ottiger, 1989).



.2 Main structural control on the distribution of the asse sediments in northern Pakistan (after Abbasi and Khan, 0).

1.1 LOCATION

As previously outlined, rocks of the Rawalpindi Group are widely distributed in the northern Pakistan. Present work, however, was done on strata of the Murree Formation at three better exposed locations (Fig. 3); the stratotype (lat. 33° 25' N and long. 72° 35'E) to the north of the Dhok Maiki village in Attock District, to the east of Ghorzai village (lat. 33° 31' N and long. 71° 44'E) on Kohat-Rawalpindi road in Kohat District, and in Pathan Algad (lat 33° 17' 20" N and long. 71° 27' E) near Braghdi village on the Kohat-Shakardarra road in Kohat District. The stratotype is located in Potwar Plateau and the other two localities are in the Kohat Plateau. All of these sections are easily accessible by metalled and unmetalled roads. Shah (1977), on the bases of faunal studies assigned an early Miocene age to the Murree Formation.

1.2 PREVIOUS WORK

The economic evaporite deposits and interesting geology of the Kohat Plateau have attracted geoscientists since late nineteenth century onward. The salt deposits of the area are referred in various published articles by a large number of geologists of the Geological Survey of India (Burnes, 1832; Karsten, 1846), though little attention has been given to the molasse sediments of the Kohat foreland basin.

Wynne (1874) described in detail the red sandstone and shales near the Murree hill station (60 km northeast of Rawalpindi) and called these as Mari Group. In this paper he described the passage from Eocene shales to Mari series. In 1877 Wynne gave Miocene age to the Mari Group and called these passage bed from marine sediments to the continental Siwalik series. Pilgrim (1910) and Pinfold (1918) concluded Murrees as entirely of continental in origin. Base of the Murree Formation at the type locality, which is conglomeratic, was named as Fatehjang zone by Pinfold. Wadia (1926) and (1931), accepted this terminology for the Kohat-Potwar province and for the Poonch area. Gill (1952) and Eames (1952) described stratigraphy of the part of the region and proposed nomenclature for the different rock units.

Systematic geological mapping of the area was carried out at a scale of 1:125,000 in 1960 by the Geological Survey of Pakistan and United States Geological Survey (Bakr and Jackson, 1964; Rashid et al., 1965; Meissner et al., 1974 and Calkins et al., 1975).

Meissner et al., (1974), mapped the Kohat quadrangle and worked on the stratigraphy of the area. Finally in (1977) Stratigraphic Committee of Pakistan named these rocks as Murree Formation and approved the term Rawalpindi Group which was suggested by Pinfold (1918) for the Miocene rocks comprising the Murree Formation and the Kamlial Formation.

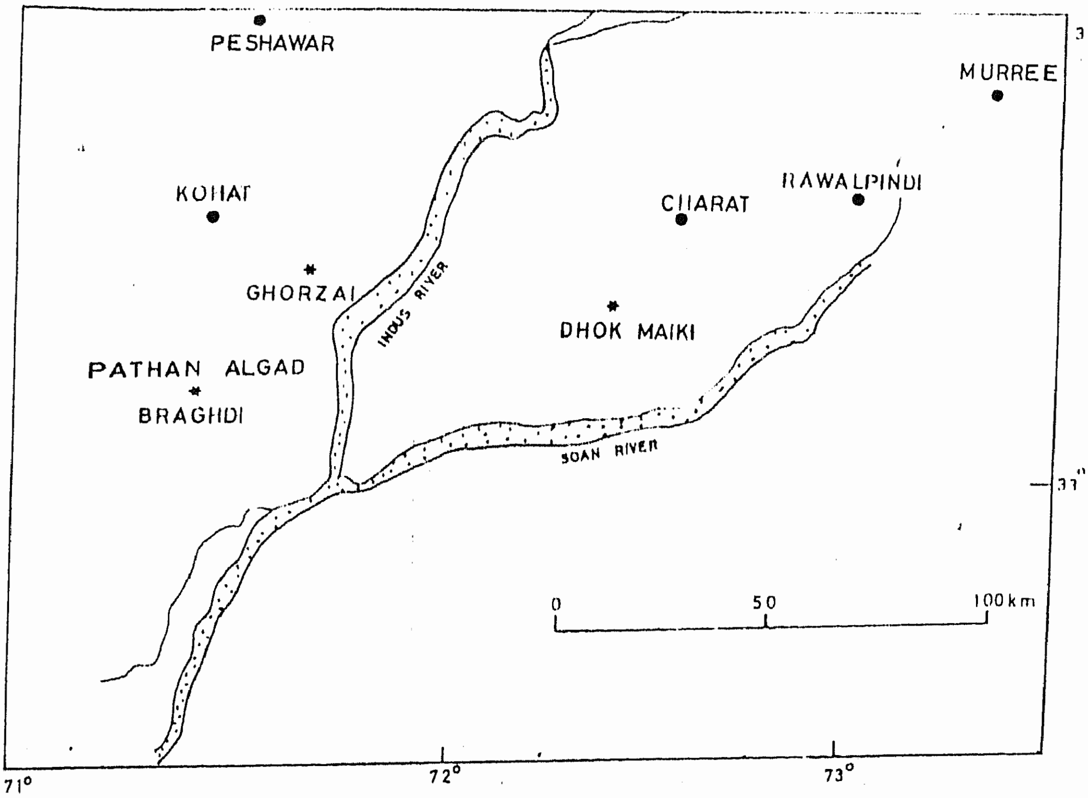


Fig. 3 Simplified map showing location of the three sections marked by asterisks.

Subsequent workers including Calkins et al., (1975), Latif (1970), Fatmi (1973), Meissner (1974), and Tahirkheli (1982), considered Murree Formation as continental deposits. Wells (1983,1984) discussed the depositional environments of the early Eocene rocks particularly the Kuldana formation. Bossart and Ottiger (1989) described the rocks of the Murree Formation as indicator of the descending foreland basin of late Paleocene to middle Eocene age. Their work is based on detailed sedimentological and micropaleontological studies. Ahmad (1989) worked on the structural geology and sedimentology of the area surronding the Shakardarra town in Kohat Plateau for his Ph.D dissertation, but he has not done the sedimentological studies of the Murree Formation

1.3 PALEONTOLOGY

Generally the formation is poorly fossiliferous. Fatmi (1973) described Eocene derived fossils, pieces of silicified wood, plant remains and frog and mammal bones. In the north near Balakot the formation has yielded nummulites and assilines (Bossart & Ottiger, 1989). But in the studied area the formation consists only of trace fossils. Vertical, oblique and horizontal tube like burrows are present. In the Fatehjang member at the stratotype mammal remains including **Anthracotherium Bugteinsis, Hemimeryx sp. branchyodus, gigantus, B.cf. anfricanus, Paleochoerus Pascoci** and **Teleceras Fatehjangensis**, are described by Fatmi (1973).

1.4 SCOPE AND PURPOSE OF THE PRESENT WORK

In the past there is not any work done on the sedimentology of the Murree Formation in Kohat-Potwar Province. The purpose of the present work is two fold:

1:- **To determine the depositional environments.**

For this purpose outcrop sections were measured. Lithologic characteristics and primary sedimentary features were recorded. On this basis lithofacies were developed and their depositional conditions were delineated.

2:- **To determine the provenance.**

For provenance studies sixty samples were collected from the field, of which thirty thin sections were prepared. Detailed study of the thin sections was done for determination of the provenance.

1.5 LAYOUT OF THE THESIS

Chapter 1 gives the general informations about the area, its regional geology, stratigraphy, previous work, purpose and methodology.

Chapter 2 describes in detail all the three sections, their lithostratigraphy, their sand-bodies and paleochannel analysis.

Chapter 3 discusses in detail generalized standard lithofacies and their depositional interpretation.

Chapter 4 deals with the provenance of the formation.

Chapter 5 presents the summary and conclusions of this research.

1.6 FIELD AND LABORATORY TECHNIQUES

Field work was basic in the present research. It included detailed vertical lithologic log preparation and the recording of primary sedimentary features such as bed thickness, beds lateral change in thickness and pinching, characters of bedding planes, internal arrangement within individual beds like horizontal lamination, cross-bedding etc. and color.

Thin sections obtained from selected samples were examined using an Olympus petrographic microscope. These studies were done primarily for provenance determination. Point counting of the grains was done. An average of 250 counts per samples were made depending on the grain size.

1.7 FACIES AND FACIES TERMINOLOGY

The use of term facies is restricted to the description of the rocks according to their color, nature of bedding, composition, texture, fossils and sedimentary structures. Ideally a facies should be a distinctive rock that form under certain conditions of sedimentation reflecting a particular process or an environment. The rock type observed in the study area all result from deposition in a fluvial environment. The terminology of Friend et al., (1979) has been used to describe various aspects of river flow and sand-body geometry (Fig. 4).

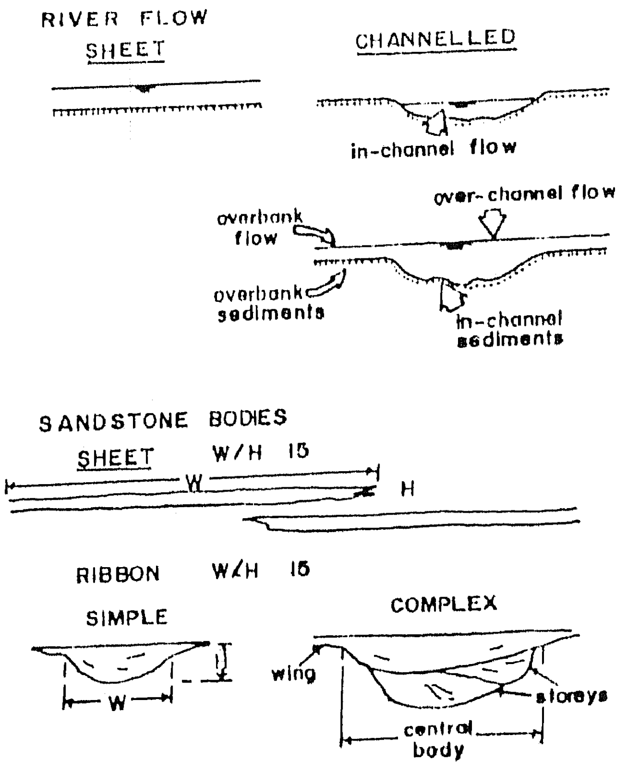


Fig. 4 Various aspects of river flow and sand-body geometry (after Friend et al., 1979).

1.8 REGIONAL GEOLOGICAL SET-UP

The northern Pakistan occupies an important position in the tectonic set up of the central Asia. Tectonic junction of different interacting plates and microplates is present on an area of about 800,000 square km (Farah et al. 1984), with the following two types of plate boundaries;

1. Convergent plate boundaries are characterized by continent-continent collision.

2. Transform boundaries (the Chaman Transform zone) characterized by very large strike slip and lesser thrusting.

The Indo-Gangetic foreland basin was formed as a result of collision of the Indian plate with the Eurasian plate during early Eocene or late Paleocene time (Molnar and Tapponier, 1975). This collision has shortened the crust and has developed an extensive system of southward directed thrusts and associated folding (Coward et al., 1982; Greco et al., 1989). These thrusts include the Main Karakoram Thrust (MKT), the Main Mantle Thrust (MMT), the Main Boundary Thrust (MBT) and the Salt Range Thrust (SRT) (Fig. 2). In India and Tibet the Indus Tsangpo suture marks the subduction zone of the two plates (Gansser, 1977) but bifurcates into Main Mantle Thrust and Main Karakoram Thrust in Northern Pakistan (Tahirkheli et al., 1979) (Fig. 1). Between the MMT and MKT are the rocks of the Kohistan island arc of late Cretaceous age. Subduction of the Indian plate beneath Kohistan island arc along the MMT, during the late Eocene, was the beginning of the continent-continent collision (Tahirkheli, 1979, 1982).

The MKT separates the Asian plate from the Kohistan island arc. The rocks of the Asian plate are composed of gneisses, slates, marbles and quartzite that range in age from late Paleozoic to Early Tertiary (Tahirkheli, 1979). The Kohistan island arc mostly consists of amphibolites, diorites, metanorites (pyroxene granulites) and associated volcanic rocks (Tahirkheli, 1979). The Indian plate, at various intervals, consists of various thrust faults, e.g., the Main Boundary Thrust and Salt Range Thrust (Fig. 3).

The MBT separates the pre-collision Paleozoic and Mesozoic sedimentary rocks of the Indian plate from the younger post-collision Himalayan molasse sediments. The MBT in the south is divided into several branches which are separated by deformed terrains, which constitutes the MBT zone. The major faults from north to south are Panjal Fault, Islamabad fault, Jhelum and Salt Range thrusts. Potwar plateau and Kohat plateau are located between these faults (Fig. 2).

Sedimentary and metasedimentary rocks of the Indian plate to the south of MMT form the Lesser Himalaya in Hazara and Swat

(Tahirkheli, 1982). Though molasse sedimentation started just after the collision between Eurasian and Indian plates, but it reached Kohat-Potwar Plateaus much later. The molasse sediments thin out in western Kohat. Molasse sedimentation in the Trans-Indus Ranges started later than the Kohat-Potwar Plateaus as the depocentre migrated south- southwestward (Raynold & Johnson, 1985). In the Kohat-Potwar Plateaus sedimentation was slow during the deposition of the Rawalpindi Group and lower Siwaliks and increased up to 0.30 mm/year during middle Siwaliks times (Johnson et al., 1985). The higher uplift rates coupled with the increased rates of basin subsidence resulted in the increased rates of sedimentation.

The Kohat Plateau in itself is a small scale fold thrust belt where the internal deformation is significantly higher. Eocene evaporites and Miocene molasse sediments are juxtaposed along the major thrusts of the plateau.

The Rawalpindi and Siwalik groups build up a considerable part of the sub-Himalaya forming a broad range along the southern margin of the main Himalayan ranges limited in the north by the Main Boundary Thrust (MBT) (Fig. 2) (Bossart and Ottiger, 1989).

The Murree Formation exposed in Kohat is a part of the Kohat quadrangle. The Kohat quadrangle is underlain by sedimentary rocks ranging in age from Jurassic to Pliocene. The sedimentary sequence in the quadrangle has a stratigraphic thickness of more than 6098m

(Meissner et al., 1974). The northern and southern flanks of the quadrangle are in faulted contact with younger rocks. The Miocene rocks are represented by the Rawalpindi Group which unconformably overlies the dominantly marine Eocene sequence (Tanoli et al., 1993).

CHAPTER 2

SEDIMENTOLOGY OF THE SECTIONS

The strata of Rawalpindi Group, the earliest Hiamalayan molasse sediments in north Pakistan, resulted due to collision between the Indian and the Eurasian plate (Powell, 1979). Rawalpindi Group consists of two formations; older Murree Formation and the younger Kamlial Formation (Tab. 1.1).

Present study deals with the Murree Formation and is based on three well exposed sections; the stratotype, near the village of Dhok Maiki in the Attock District (Lat. 330° 25° N long. 72° 35° E), in the east of Kohat near the village of Ghorzai on Kohat-Rawalpindi road (Lat.33° 31° N long 71° 44° E), and in the Pathan Algad to the northwest of the village of Braghdi on Kohat-Shakardarra road (Lat.33° 17' 20" N long 71° 27° E)(Fig. 3).

The strata of the Murree Formation are exposed in the Kohat-Potwar Province, Salt range, Hazara-Kashmir Syntaxial belt, Jammu and the north Indian plain (Fig. 1). It consists of reddish brown and grey sandstone, siltstone, clay and conglomerate.

Although structural and stratigraphic studies of the Murree Formation and related strata have been published (Fatmi,1973; Meissner et.al.1974; Bossart and Ottiger, 1989; Ahmed, 1989), but there has been no detailed study of its depositional environments, in the Kohat and Potwar area.

In the proceeding pages all the three sections have been described and interpreted with respect to the depositional environments.

2.1 DHOK MAIKI

DESCRIPTION

At Dhok Maiki the Murree Formation consists of 5 major sand-bodies. These sand-bodies range in thickness from 4m to 62m (Fig. 5). Here the Murree Formation unconformably overlies the Eocene Chorgali Formation.

The sand-body DM1 which is the thickest lies at the base and is up to 62m thick (Fig. 5). It starts with a 3m thick conglomerate which consists of reworked limestone clasts and fossil fragments from the Chorgali Formation., These clasts are up to 2cm in size, are sub-rounded to rounded (Fig. 6). This zone has been designated as Fatehjang member due to its sandstone, conglomerate and larger foraminifers of Eocene age (Shah, 1977).

Basal 10m of the sand-body DM1 is predominantly conglomerate with subordinate sandstone. The conglomerates consists of various sedimentary structures such as cross-bedding, horizontal-bedding and are massive as well. The cross-beds are trough in nature, individual sets up to 1m wide and 25cm thick have been recorded

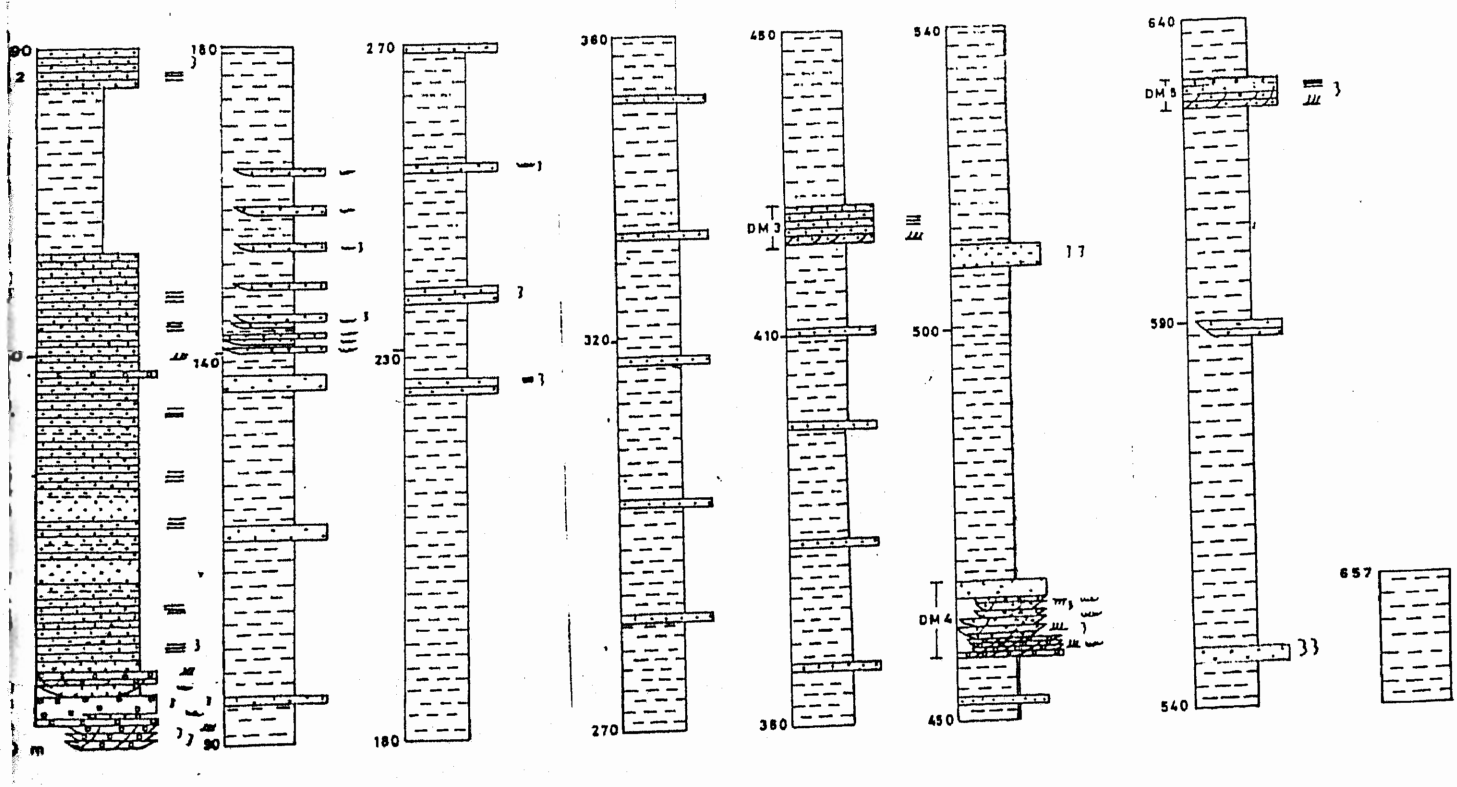


Fig. 5 Composite lithologic profile of the Murree Formation at Dhok Maiki. The clay horizon of the sections are mostly covered.

Fig. 6 Conglomerate at the base of the Murree Formation at Dhok Maiki showing clasts up to 2cm, and which are sub-rounded to rounded.

(Fig. 7a). These conglomerates generally have erosive bases, and individual beds have maximum thickness of up to 1m.

Upper portion of the sand-body DM1 is predominantly sandstone. These sandstones have transitional to sharp bases and are plane-bedded, massive and lenticular at places (Fig. 7b). They extend laterally more than the conglomerates. These sandstones are thinly bedded, from 1cm to 4cm (Fig. 7c) and in the upper portion the individual bed thickness is up to 70cm (Fig. 7d). At 50m level within this sand-body a conglomerate horizon is again present which is 50cm thick with erosional base and has clasts up to 2cm in diameter. These clasts are angular to sub-rounded. The conglomerate is faintly bedded to massive.

These conglomerates, where present, makes the base of the sedimentary cycle and therefore, mark the initiation of the fining-upward sequence. In general there are three fining upward cycles in this sand-body, which get thicker in size vertically upward. At the basal portion of this sand-body the lateral extension of these conglomerates increases upward.

The top of this sand-body terminates into 25m thick horizon of red massive clays.

The sand-body DM2 is 5m thick. It has erosive contact with the underlying red massive clays, and consists of sandstone which extends more than 100m laterally. In the lower parts the sandstone appears faintly-bedded but vertically upward the beds appear

Fig. 7 Sand-body DM1 at Dhok Maiki: (a) Trough cross-bedding and ripple lamination in the basal conglomerate. (b) The photograph showing transition of conglomerate at base into composite bedded channelized sandstone beds. (c) Thin bedded sandstone in the lower portion of the sand-body. (d) Thick bedded sandstone in the upper portion of the sand-body.

20cm thick and 1.5m wide. Towards the SW from the main conglomerate body, these Conglomerate beds are intervened by sandstone beds (Fig. 8a). The cross-sets changes from troughs in the lower portions of conglomerate and sandstone beds to megarippled in the middle and low angle plane-beds, to plane-beds and massive sandstone at the top (Fig. 8b). These conglomerate beds thin out towards NE and SW from the main body. The conglomerate is overlain by 7m thick sandstone unit. This sandstone is trough cross-bedded in its lower portions mega rippled/planar cross-bedded in the middle portion and passes vertically upward into horizontal-bedded and massive at the top. The cross-bed sets are up to 20cm thick and up to 1m wide. To the NE from the main exposure the sand-body is low angle cross-bedded and rippled (Fig. 8c). This sand-body once again terminates by passing into thick red massive clays 40m thick unit.

Sand-body DM5 is sandwitched between the massive red clays. It is 4m thick and is traced laterally for more than 100m. Because of poor exposures, sedimentary features could not be observed in detail, however, it is trough cross-bedded in the lower portions and horizontal-bedded in the upper portions. Bioturbation at places is visible in this sand-body.

Besides these major sand-bodies, there are minor sand-bodies shown in the vertical profile, which are 1 to 2m thick occassionally 3m. Mostly of these are massive in nature, some of these show bedding and bioturbation. Since no useful information could be gathered for sedimentological purposes, therefore are not explained in detail.

Mostly the formation consists of massive red clay intervals which are up to 60m thick and are mostly covered. The top of the formation is covered.

INTERPRETATION

Conglomerates of the sand-body DM1, at base of the formation are associated with erosional surfaces, therefore, are interpreted as channel lags. The clasts generally are extra basinal, consisting mostly oflimestone clasts and fossils reworked from the underlying Chorgali Formation. The clasts were moved only during high flood conditions by rolling on floor of the channel, and were settled down as the water velocity decreased. This conglomerate was developed during more than normal flood conditions which eroded sediments from distant source areas or were supplied by the surrounding elevated rocks, and incorporated them as a stream-load. In summary these conglomerate beds up to basal 9m level represent successive high energy conditions in the stream, each event eroding upper parts of the previously deposited sediments which were relatively fine-grained and product of normal flow conditions (Qureshi and Tanoli,1992).

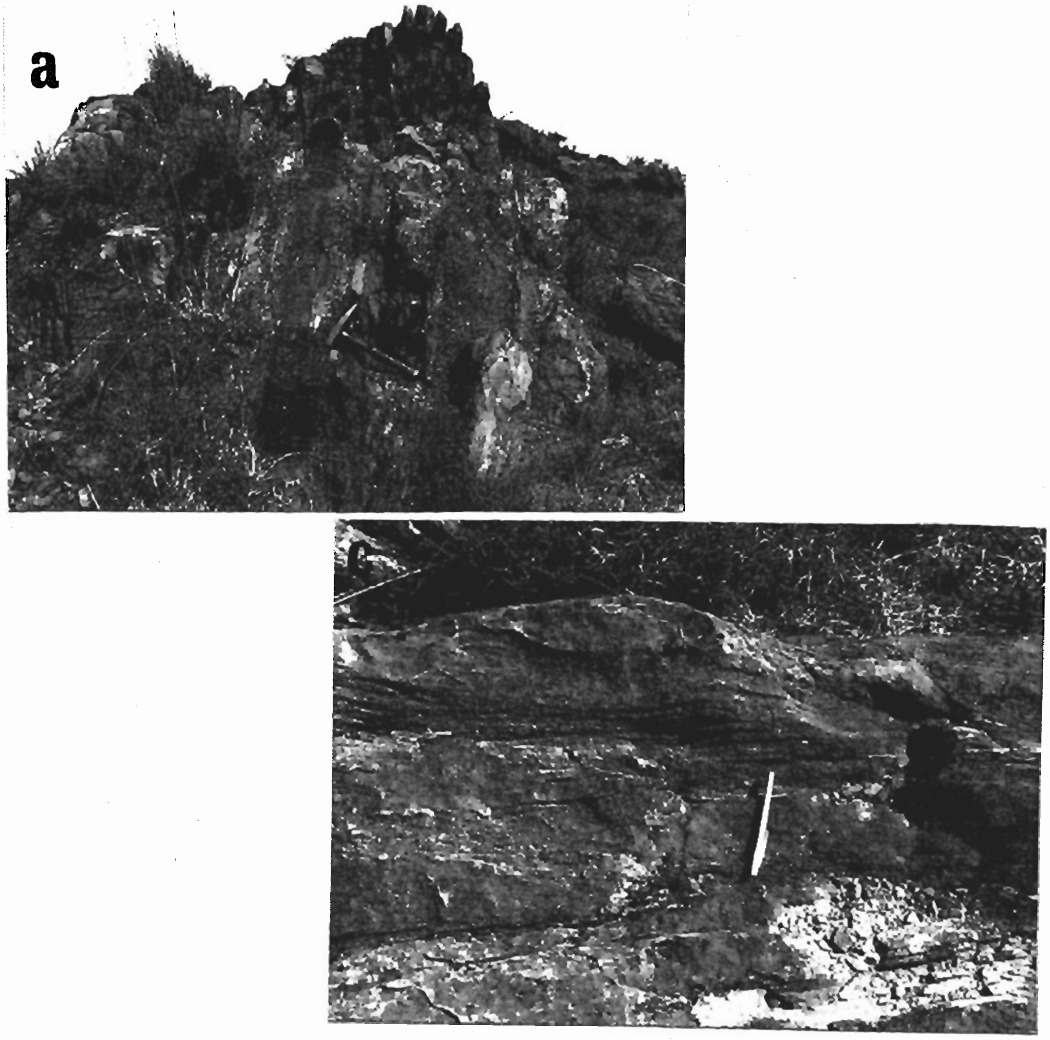


Fig. 8 Sand-body DM4 at Dhok Maiki (a) Photograph showing amalgamation of interbedded conglomerate and sandstone beds (b) Photograph showing trough cross-bedding in the lower portion and megaripples/planer cross-bedding, low angle plane bedding, horizontal-bedding and massive at the top in a conglomeratic horizon. (c) Photograph showing ripple cross-lamination (pen is 15cm long).

The multistorey conglomerates at the base resulted either from sudden recurrence of the waning flood to high stage condition, resulting in the erosion of the previous deposits (Mader, 1985) or, from lateral merging of two successive gravel veneers by pinch out of interbedded sand.

The conglomerates and interbedded sandstones were deposited as the channel accreted laterally. As a result the conglomerate was deposited at the base of the channel which now made the base of the developing point bar. Lateral channel shifts deposited the overlying sand. This process was repeated time and again giving rise to the interbedding of conglomerate and sandstone. The upper part of the bar was more or less eroded away during high intensity flood currents leaving behind the lower part of the bar only. Sedimentary cycles consisting of alternating conglomerate and sandstone confirms repeated phases of intraformational reworking, channel shift, lateral and vertical erosion.

The cross-bedded conglomerate at 8m and 9m level in the sand-body DM1 consists of clay clasts and is interpreted as deposit of the channel itself These clasts originated either by bank collapse or by erosion from the flood plain areas. Inverse increase of clast size in these conglomerate beds suggests their deposition during increasing flow intensities.

Horizontally-bedded sandstone at 10-14m level are the result of higher velocities at shallower depths, which can occur at various river stages and therefore, can be formed at low as well as high on the point bars (Walker and Cant, 1984). The preservation of these features is favored by lateral and downstream accretion of the point bars. Harms and Fahenstock (1965) suggested, horizontal-beds are the result of upper flow-regime plane bed conditions, usually found in shallow water near the top of the point bars. Smith (1971) suggested that horizontal-bedding is produced in shallow water, on top of the point bars, where increasing flow velocities result from large volumes of water being forced into confined space. The horizontal-bedding therefore, is the result of upper flow regime conditions suggesting fast flow and possibly shallower depths. The channel at this stage appears to have stabilized and possibly broadened which is suggested by the absence of the conglomerates.

Sandstone unit from 17m level consists of composite sandstone beds which are horizontally-bedded as well as massive with smooth and broad lower bedding plane, which most probably represent shallow and broad channels which were developed by eroding the marginal flood plain area, above the point bars and channel sequence (Qureshi and Tanoli, 1992). Massive beds might have developed by rapid dumping of sediments during flood conditions.

The uppermost conglomerates at 50m level consists of silt and clay clasts, are intraformational in nature and represent more than normal flow energies. These intraformational conglomerates are similar to those found in the lower reaches of river systems, and are concentrated at the base of point bars (Bluck, 1971). Intraformational conglomerates have also been observed in point bars of ancient streams, where they have been interpreted as channel lag deposits (Allen, 1970a). The silt and clay pebbles may have originated from bank erosion (Bluck, 1971) or erosion from the flood plain area. Overlying sandstone is interpreted as point bar deposit. Plint (1983), suggested that horizontal bedding and massive sandstone is produced on the top of the point bars in shallow water. The sand-body grades laterally into thick red massive clays of flood plain origin which marks the termination of sand-body DM1.

Sand-body DM2 which consists of faintly bedded to massive sandstone scours into the red massive clays. It lacks coarse-grained sediments at the base suggesting that the energy conditions were not too high to deposit coarse-grained sediments. The depositional processes for horizontal-bedding has already been described in the DM1.

Overlying alternating beds of sandstone and dominant clay up to 410m level are interpreted as crevasse splay or levee deposits within the flood plain area. Stewart (1981) considers such deposits as levee deposits accumulated adjacent to the river channel. Relatively coarser sediments were transported by sheet flow over channel banks during flood stages and deposited as thin layers in levee flanks. The alternation of coarse and fine grained layers is, therefore, suggestive of a seasonal control on sedimentation (Stewart, 1981). Crevasse channels are formed by breaching of major distributory channel banks during high floods. The channels are scoured by the flood waters and are filled as the flow power decreases.

The dominant lithology of the Murree Formation at the type locality is red clay, which is interpreted as flood plain deposits. This clay settles out of suspension from the overbank flows after the coarser sediments have been deposited on levees and crevasse splays. In the meandering channels thick flood plain deposits are sandwitched between channel deposits. However, thick flood plain deposits are produced if streams become more or less fixed in their position and longer periods are available for deposition in the flood plain. Repetition of red clays may show abandonment as well as re-establishment of the channel.

Sand-body DM3 makes a erosive lower contact with the red clays. In this sand-body channels could not be observed, rather the sand-body has appearance of being deposited by sheet flow in flood plain areas in a broad and shallow depression. Allen (1983) suggests that more extensive sheet like members reflect more random patterns of channel shifting and migration of low sinuosity sandy streams.

The sand-body DM4 begins with erosively based 2m thick conglomerates. These conglomerates are interpreted as channel floor lag deposits. The conglomerate is overlain by trough cross-bedded sandstone which is related to the river migrating laterally by eroding the concave bank. Trough cross-bedding in sandstone is produced by the migration of sinuous and straight-crested dunes (Jackson 1976). Jackson (1976) found sinuous dunes in channel bends and straight-crested dunes in crossings. This trough cross-bedded sandstone overlying the conglomerates as well as megarippled cross-bedding is interpreted to have been developed in lower point bar (Allen, 1970a) or mid bar (Levey, 1978) by migrating dunes (Qureshi and Tanoli, 1992). Allen (1982) suggests that trough cross-bedding in sandstone is formed by the aggradation of linguoid to strongly sinuous current ripples, or three dimensional dunes. Megaripple cross-bedding overlying trough-bedded sandstone may suggest that the conditions were not favorable for the migration of megaripples to convert them into trough cross-bedding. That's why megaripples are preserved above the trough cross-beds.

Planar cross-bedding on the other hand indicate flow conditions of lower energy than those producing three dimensional large ripples (Allen, 1982). Low angle plane bedding overlying the megaripple-bedding in this sand-body are usually transitional both vertically and horizontally to plane-bedding (Abbasi, 1989). These beds are produced in similar fashion as plane bedding (Allen, 1984, Paola et. al. 1989). Low-angle plane beds are also formed by shallow, high velocity flow into broad shallow scours (Rust, 1984).

Coleman (1969) described its formation by the migration of the sandwaves. Plane-bedded sandstone in this sand-body on the other hand was deposited in the upper flow regime on the upper part of the point bars, and appears to be produced in shallow waters, especially across the top of the point bars where increasing flow velocities result from large volumes of water being forced into a confined space (Smith, 1971). Erosion at the base of the plane-bedded sandstone resulted during flood stages, followed by deposition of upper phase plane beds of falling stage (Allen, 1974). Massive sandstones at the top of this sand-body are interpreted as a result of rapid sediment dumping from high energy flows (Fielding, 1986), possibly at the top of point bars. Red massive clays which generally cap this sand-body are of flood plain origin and hence the termination of sand-body DM4.

Red massive clays in the upper part of the formation contain thin sandstone beds, commonly brownish grey to brown in color. deposited from suspension. These sandstone beds which are 1-4m thick, were deposited by either crevasse splays or are levee deposits (Qureshi and Tanoli, 1992) or by local stream activity in flood basin (Ahmad, 1989). Such sandstone units throughout the formation have sharp basal contact with underlying red clays. Internal structures usually contain horizontal-bedding or are massive or occasionally cross-bedded. Most of the minor sand-bodies interbedded with thick overbank fines are single storey, and appear massive either due to bioturbation or due to rapid sediment dumping from high energy flows (Fielding, 1986).

2.2 GHORZAI

DESCRIPTION

At Ghorzai the Murree Formation makes the lower contact with the limestone of the Kohat Formation. The major sand-bodies are thicker than five meters (Fig. 9) and are traced laterally for hundreds of meters. The minor sand-bodies do not exceed in thickness for more than three meters, and are of limited lateral extent and extend only a few tens of meters. The Murree Formation at this locality is generally composed of sandstone and clay with subordinate conglomerates and mainly caliche beds.

A 15 cm thick massive sandstone of the sand-body SB1G which pinches out laterally within a distance of 15m locally forms the base of the formation. At certain places the limestone of the Kohat Formation is overlain by 1m thick caliche bed which grades laterally into red clay. A conglomeratic bed which sharply overlies the caliche bed decreases in thickness from 50cm to 15cm towards east. The conglomerate have scoured into the underlying caliche, and typically consists of poorly sorted angular to subrounded, pebble size clasts of silty clay and limestone (Fig. 10a). The conglomerates generally is matrix supported. Conglomerates are impersistent and pass laterally and vertically into sands, and have pebbles up to 1.5cm in diameter. This conglomeratic bed is overlain by medium-grained, reddish brown sandstone which is 70cm thick and pinches out laterally within a distance of 30m. Overlying is a 5m thick massive sandstone with a much larger lateral extention. Though this sandstone thins and swells but is exposed laterally for more than 200m. This sandstone unit has sharp contact with the underlying sandstone and with the overlying caliche bed (Fig. 10b). This is followed at the top by a 5m thick red clay unit which is overlain by a 40cm thick caliche horizon which in turn is followed by a 5m thick red clay zone.

Sandstone of sand-body SB2G sharply overlies the caliche bed. The sandstone is medium-grained and laterally persistent for 100's of meters. The sandstone beds increase in thickness from 2cm in the lower parts to 25cm in the upper parts. The sandstone is cross-bedded, the cross-beds look like troughs. Towards the top, 6m thick horizon of red massive clay with interbedded sandstone is present. The sandstone beds in this zone range in thickness from 34cm in the lower levels to 10cm in the middle and upper levels (Fig. 10c), and pinches-out laterally over a distance of less than 30 meters. These sand beds are replaced laterally into red clays.

Sand-body SB3G consists of conglomerate at the base which overlies the red massive clays. The conglomerate has maximum thickness of 1m, which decreases to 0.5m laterally within a distance of 60m. The conglomerate is cross-bedded (Fig. 11a) and consists of clasts of up to 1cm in diameter. The cross-beds show flow direction to the SW. This conglomeratic bed is sharply overlain by a sandstone bed, in which troughs are superimposed (Fig. 11b). The sandstone is laterally persistent and is overlain by 6m thick massive red clays. Overlying the red massive clays are 10m thick interbeds of sandstone and red clays. These sandstone beds are sharply based and pinch out within 5-20m distance (Fig. 11c). The sandstone beds are separated by red massive clays of up to 40cm in thickness.

Sand-body SB4G is composed of sandstone overlain by red massive clay. Individual sandstone beds have thickness ranging from 15-30cm. Generally the sandstone beds are horizontally-bedded but appear massive near the top of this sand-body. There is an intervening clay in between some sandstone beds. The sandstone beds are bioturbated.

Sand-body SB5G is 7m thick and scours into the red clays (Fig. 12a). Sandstone in the lower 4m is cross-bedded (Fig. 12b), the sets are up to 2cm thick and dip up to 20° to SW. Some of the beds thin out laterally (Fig. 12b). The upper 3m is faintly -bedded, at some places it is massive. The beds are devoid of any intervening clay, and have thickness up to 50cm which are

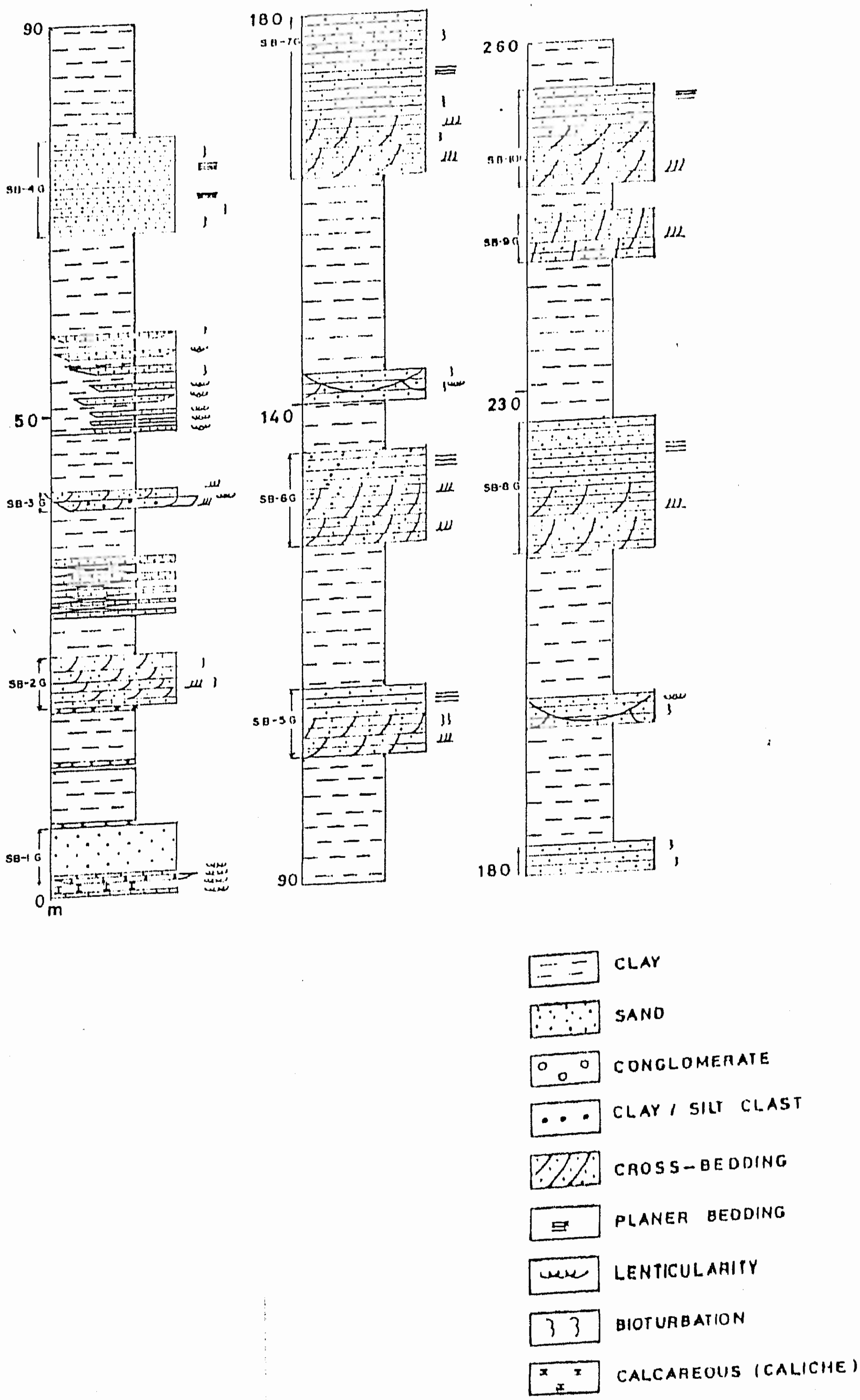


FIG. 9 Columner display of the Murree Formation at Ghorzai.

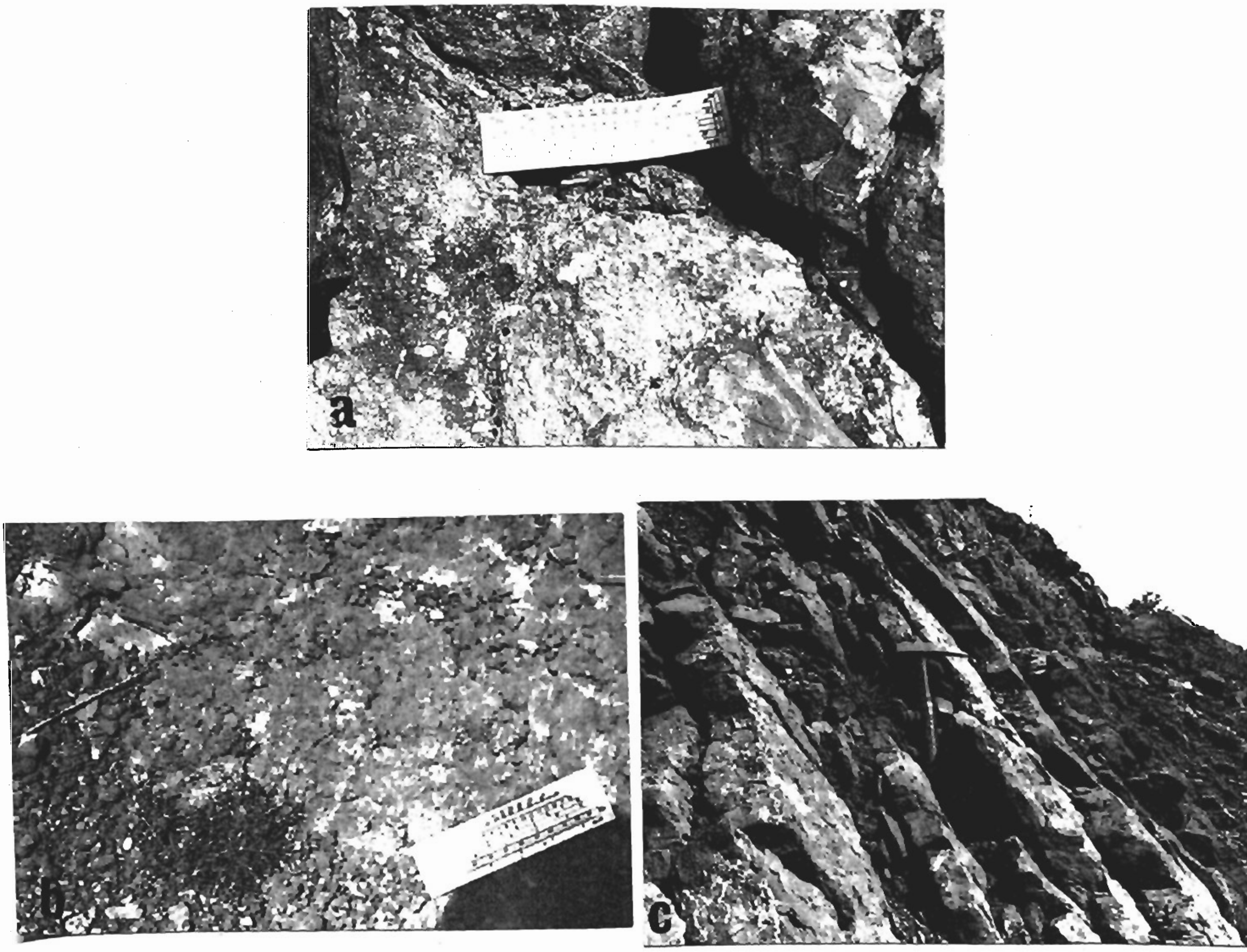


Fig. 10 Sand-bodies SB1G and SB2G at Ghorzai (a) Photograph showing clay and limestone clasts in the conglomerate of the sand-body SB1G (scale is 15cm). (b) Photograph showing of a caliche horizon in the lower portion of the formation at Ghorzai. (c) Sandstone beds in the sand-body SB2G which gets thin upwards from 34cm in the lower levels to 10cm in the middle and upper levels (Hammer is 33cm long).

laterally persistent for 100's of meters. Towards the top of this sand-body the beds are horizontally-bedded.

Sand-body SB6G is erosively based and consists both trough and horizontally laminated sandstone beds (Fig. 12c). The unit at places is composite in nature. The sand-body passes laterally into red massive clay, which is once again overlain by a 3m thick sandstone unit. Beds up to 40cm thick have been observed, which pinches out laterally within a short distance. These sandstone beds are generally bioturbated.

Sand-body SB7G is the thickest (20m thick) in this section, in which individual beds up to 80cm thick are present. The sand beds are composite in nature and has sharp erosive lower contacts. In the lower portion the beds are cross-bedded, but due to steep dips and weathering of the exposed beds the nature of the cross-beds could not be recognized. The middle portion of this sand-body is horizontally-bedded and upper 7m is massive. At places the sand-body is bioturbated.

A 3m thick sand-body sharply overlies 12m massive red clay. Individual beds having thickness of up to 30cm pinch out laterally within 100m into red clay. The sand is bioturbated due to which sedimentary structures are destroyed and only horizontal-bedding is observed.

Sand-body SB8G is 14m thick with scoured base into the underlying

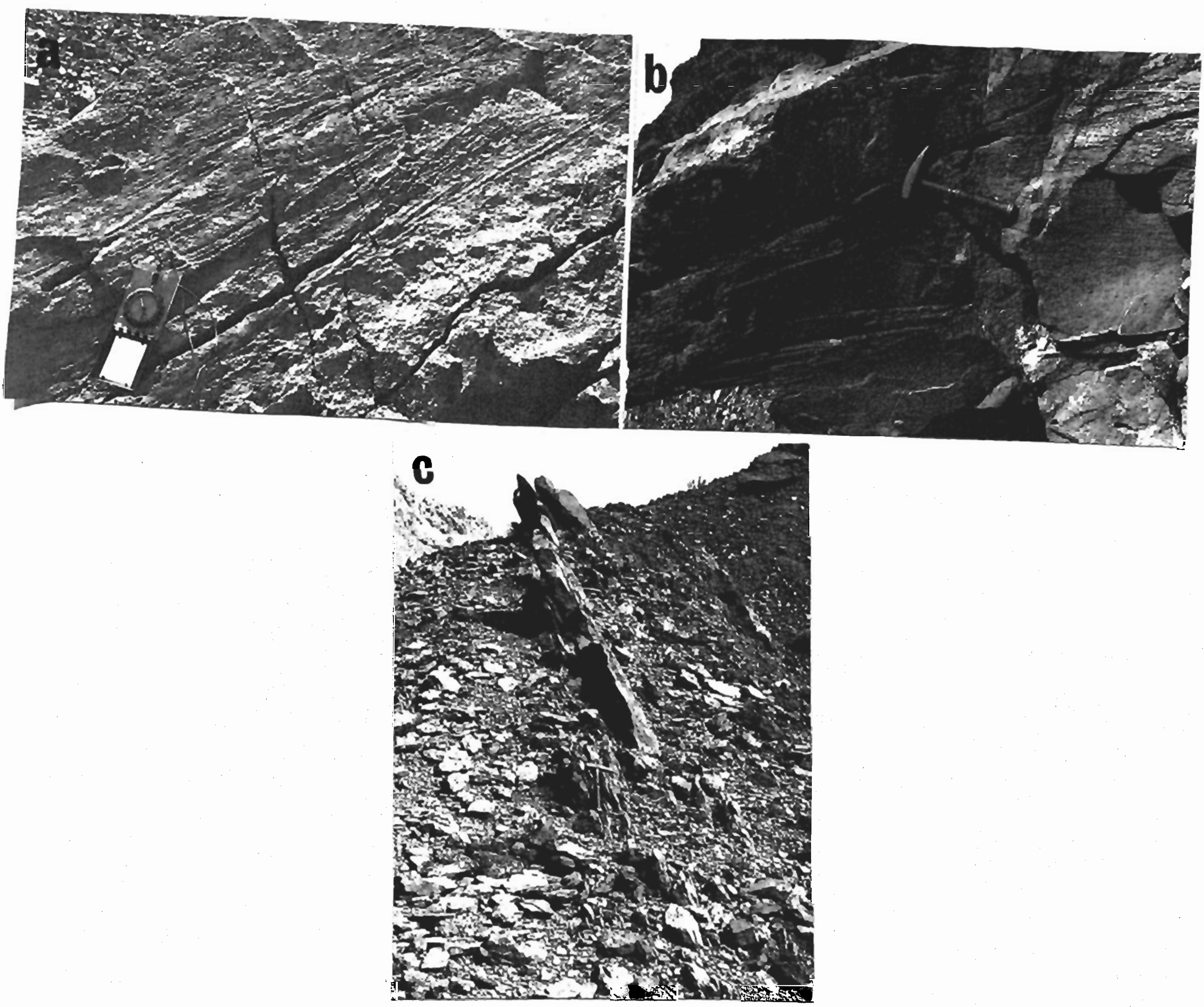


Fig. 11 Sand-bodies SB3G and SB4G at Ghorzai (a) Cross-laminated conglomerate of sand-body SB3GS (b) Trough cross-bedded sandstone in the sand-body SB3G (c) Sandstone beds interbedded with clay above sand-body SB3G.

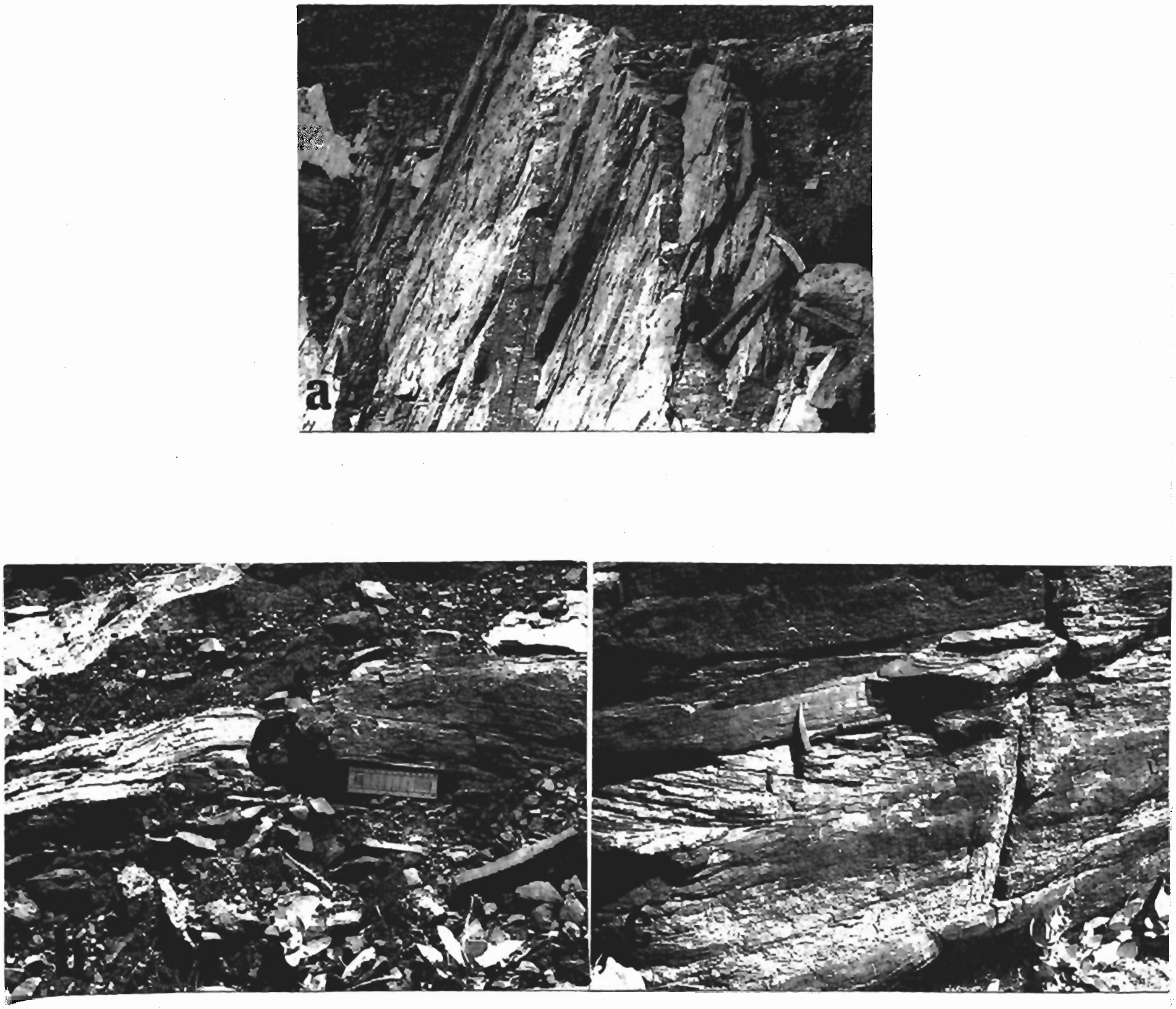


Fig. 12 Sand-bodies SB5G and SB6G at Ghorzai (a) Sand-body SB5G shows scouring into the red clays, at toe of the hammer. (b) Trough cross-bedding in sand-body SB5G. (c) The lower level in sand-body SB6G is trough cross-bedded, uppermost troughs changes laterally into horizontal beds. Top of this sand-body is massive.

clay and consists of composite sandstone beds which are medium-grained and display various sedimentary structures. The lower portion of the sand-body is cross-bedded, in which the sets are up to 25cm thick and dip up to 23°to the SW. The cross-bedded sandstones are overlain by horizontally-bedded sandstone.

The beds range in thickness of up to 40cm and have sharp bedding planes. These beds are laterally traceable for 100's of meters, but thin and swell laterally. The upper 3m of this sand-body consists of massive sandstone.

Sand-bodies SB9G and SB10G are the uppermost sand-bodies. The former sand-body is 5m thick and is poorly exposed on the surface due to which nature of the cross-beds could not be identified. The SB10G is 10m thick, the lower portion of which is cross-bedded. Some of the beds pinch out laterally. The individual beds range in thickness from 5cm to 33cm. The cross-sets are thick up to 25cm and dip up to 25° to the SW. The upper portion of this sand-body is horizontally-bedded.

INTERPRETATION

The lithofacies in the Murree Formation at Ghorzai section are similar to many fluviatile deposits described previously (Stewart, 1981; Plint, 1983, Walker, & Cant, 1984). The lithofacies association and fining upward cycles suggest that these sediments were deposited by the meandering streams (c.f. Walker and Cant, 1984). In general the formation consists of 45 percent of sandstone and conglomerate and 55 percent of clay. The sand-bodies are thin in size in the lower levels and get thicker in the middle and upper levels. The sandstone in this section is medium to coarse-grained. Only two conglomerate units are present within the section which lie in the lower portion of the formation.

The paleo-channel studies suggest that the deposits of the Murree Formation at Ghorzai resulted from the combination of bed-load, mixed-load and of suspended-load channels. Generally thick sand-bodies resulted from bed-load deposits, sand with sub-ordinate clays were the result of mixed-load channels and thick clay rich deposits resulted from suspended-load channels (Galloway, 1985).

A massive lenticular sandstone at the base of the formation is interpreted to have been deposited in proximal flood plain area as a crevasse splay or levee deposit. This is further supported by the overlying either locally caliche or red massive clays. The calcareous horizon typically develop in flood plain areas due to exposure to dry climates for a longer time in soils with low organic contents (Reineck and Singh, 1980).

The sand-body SB1G started by scouring into caliche/red clays of the flood plain. Scoured surfaces in the fluvial cycles are observed on the floors of the meandering river channels (McGowen and Garner, 1970). The conglomerates commonly associated with the scoured surfaces are inferred as a channel-floor lag (Freshney, 1970; Leeder, 1973; Mader, 1985). The clasts of the conglomerates in sand-bodies SB1G and SB3G are concentrated on the floor of the channel and were moved only during high flood stages by rolling on the floor of the fluvial channel. Depending upon the availability of the clasts and competency of flow the conglomerates either spread out as a continuous sheet or are concentrated into an isolated lenses. Shape of the clasts depend mainly on the transport history. Proximal clasts are generally more angular than the distal ones. The limestone clasts in the conglomerates are mainly reworked from the underlying Eocene formation and clay silt clasts from the cut banks of the channel. These conglomerates suggest a new river course and a major lateral shift in the river channel. The sandstone above the conglomerates gets more laterally extensive towards the top confirming successive broadening of the channel. The massive nature of the beds at the top of the sand-bodies could be due to rapid sediment dumping from the high energy flows at top of point bars (Fielding, 1986). Caliche bed at top of this sand-body suggests a long exposure to the dry climates and therefore abandonment of the channel and major shift in stream course and termination of sand-body SB1G.

Sand-body SB2G indicates another episode of major channel shift in the Ghorzai area. The basal position of this sand-body was a lower to middle part of the point bar. Sand transportation was dominantly by dune migration which is supported by the presence of medium-to-large trough cross-bedding (Galloway, 1985). The sand was thus transported as bed-load. During the normal discharge in the channel, the typical bedform on the channel floor consisted of sinuous-crested dunes ranging in height from 30cm to 1m. Preservation of these dunes on the lower-middle parts of the point bar resulted in the trough cross stratification (Walker and Cantt, 1984). This sand-body passes laterally into flood plain deposits. In the upper parts interbedded sandstones and clays are interpreted as crevasse-splays or levee deposits. Lenticular sandstone occasionally occurring in flood plains are interpreted as crevasse splay deposits (Mathisen and Vondra, 1983). Leeder (1974) has also suggested that lenticular sandstones in flood plain deposits may be crevasse splays deposits if they are laterally limited in extent. This part is the result of vertical accretion deposits produced during successive floods. Thicker beds (up to 34cm) representing relatively proximal or more powerful floods and the thinner (up to 10cm) beds relatively distal or weaker floods (Graham, 1983). Plint (1983) suggests that such sands could have been transported as sheet flows over channel banks during flood stages and deposited as thin layers down levee flanks. This facies pass laterally into red massive clay of flood plain area and therefore makes a complete sedimentary cycle.

The conglomerate at the base of the sand-body SB3G is interpreted as intraformational in nature. It consists of red silt\clay clasts. Mader (1985) pointed out that thicker sequences of intraformational conglomerates reflects continuous lateral erosion and undercutting of the river which results in supply of silt/clay over longer period of time. On the other hand thin layers of intraformational conglomerates intercalated into sandy sequences reflect discrete phases of channel shifts alternating with periods of watercourse stability and only negligible lateral erosion. This single storey 1m thick conglomerate developed during major channel shift which eroded sediments from the flood plain area and incorporated them as a stream load (Qureshi and Tanoli,1992). Miall (1978) interpreted such conglomerates as channel fills. The 1m thick trough cross-bedded sandstone overlying this conglomerate was deposited as the river migrated further laterally by eroding the concave bank (Mathisen and Vondra, 1983). This sandstone therefore, is deposited as a result of dune migration and represents the lower to middle part of the point bar (Galloway, 1985). The sand was transported as bed-load and deposited as a laterally accretionary deposit. Collinson (1986) suggests that trough cross-bedding is produced by the migration of the dunes with sinuous crest-line or sand waves with more commonly three dimensional linguoid form. According to Jackson (1976) and Levey (1978) such trough cross-bedding is produced by the migration of sinuous and straight-crested dunes. Jackson (1976) reported sinuous dunes to pre-dominate in channel bends and straight crested dunes in crossings. Walker and Cantt (1984) also suggested that above the channel lag the sand is transported as a bed-load and consists of sinuous crested dunes, preservation of these dunes results in trough-cross stratification. This sand-body passes upward into red massive clays of flood plain deposits. This red clay falls out of suspension after floods as a vertical accretion deposits. It passes upward into interbedded sandstone and clay. This interbedded sandstone and clay is already interpreted as a crevasse splay or levee deposits in sand-body SB2G.

The sand-body SB4G is interpreted as a part of point-bar deposit, the horizontal beds in the sandstones are developed in the middle and upper part of the point bars. In this part of the point bar water is shallow, having high velocity under the upper flow regime plain bed conditions (Qureshi and Tanoli, 1992; Plint, 1983; Stewart,1981). The massive beds at the top could be due to rapid sediment dumping from high energy flows or the primary sedimentary structures were destroyed by bioturbation (Fielding, 1986).

Sand-body SB5G consists of lower trough-cross bedded sandstone and upper horizontal-bedded sandstone. The lower trough-cross-bedded sandstone are already described in the sand-body SB3G, which represents a part of lower-middle portion of a point bar. The upper horizontal-bedded sandstone developed in the upper parts of the point bar in shallow water and high velocity under the upper flow regime conditions (Qureshi and Tanoli, 1992). Horizontal-beds which results from the upper flow-regime are usually found in shallow waters near top of the point bars (Harms, McKenzee & McCubbin, 1963; McKee et al., 1967).

Sand-body SB6G mainly represents a point bar. The deposition of the lower trough cross-bedded sandstone has already been discussed in detail in sand-bodies, SB2G, SB3G and SB5G. The horizontally-bedded sandstone in the upper part of the sand-body was deposited in the upper parts of a point bar under upper flow-regime plane bed conditions which already has been discussed in sand-body SBG5. Walker and Cantt (1984) suggest that a particular combination of depth and velocity required to produce a plane-bed can occur at various river stages and hence parallel lamination can be formed both in lower and higher portions of the point bars.

Above this sand-body 3m thick sandstone unit is suggested to have formed as crevasse splay or levee deposit, in which sand deposition is mainly by vertical accretion processes. The processes of deposition have already been discussed in detail above in sand-bodies SB2G and SB3G.

Sand-body SB7G is the thickest sand-body at this section. It has a maximum thickness of 20m and indicates a more broad channel with more lateral shift. The sand transported mainly as a bed-load by lateral accretion processes. The depositional processes for the lower trough cross-bedded sandstones, middle horizontal cross-bedded sandstones have been discussed already in the sand-bodies

SB2G, SB3G, SB4G, SB5G and SB6G. The upper massive sandstone could be due to bioturbation which destroyed the original structures or alternatively primary structures were never developed due to rapid sediment dumping from high energy flows (Fielding, 1986).

The 3m thick sandstone above this sand-body is very much similar to the one on the upper portions of the sand-body SB6G, therefore, has been deposited under similar conditions. Sand-body SB8G has developed from somewhat similar depositional processes as that of sand-body SB7G.

Sand-body SB9G was deposited under the same environments of sand-body SB2G and sand-body SB10G is very much similar to sand-bodies SB5G and SB6G.

The red massive clays which forms a considerable part of the formation are interpreted as flood plain deposits. During flood conditions in river, the main channel may not be able to hold the flow of water and results in the over flow out of the channel. This results in fine-grained sediments deposition as the flood water looses its competency with distance. The subsidence of the flood results in the deposition of thick fine-grained sediments in the flood plain areas. Sharp bases with an abrupt change from sand to red clay strongly suggests rapid abandonment of the channel. Thick clay units suggest that the river may have stabilized in one position for a longer time.

The caliche beds in the lower levels of the formation suggest that the environments were semi-arid to arid. The fluctuation in the ground water table and drying at the surface resulted in the formation of caliche (Reineck and Singh, 1980).

2.3 PATHAN ALGAD

DESCRIPTION

The Murree Formation in Pathan Algad is composed of sandstone, siltstone, clay and conglomerate (Fig. 13). At base of the Murree Formation is a conglomerate body 50cm thick consisting of 10-15cm thick apparently laterally pinching conglomerate beds.

The clasts are of the underlying Kohat Formation and are up to 10cm in diameter. This conglomerate is overlain by 1m thick poorly developed semilithified calcareous clay horizon which is followed by 12m thick massive red clay, and marks the initiation of the Murree,s deposition (Fig. 14). Overlying this clay is the major sand-body SB1.

The SB1 is 21m thick and has a sharp erosional contact with the underlying clay (Fig. 14a). Although the unit is composite-bedded, without any intervening shale, still the individual beds can be delineated. The basal sandstone bed has scoured into clay. The sandstones are mainly cross-bedded but bioturbation has obscured the primary structure in several beds. Above the 6m level within this sand-body 2.5m thick pebbly sandstone and conglomerate is present (Figs. 14a & 15). Red siltstone or clay clasts of up to 20 cm in diameter are locally concentrated at the base of several beds (Fig. 14c). There is 1m thick horizon of three composite conglomerate beds that pinch out laterally over a short distance and are represented by lateral equivalent sandstone beds (Fig. 14a). The conglomerate in the thicker portion consists of rounded 1 to 2cm in diameter maroon siltstone pebbles. A 10cm thick bed of the conglomerate continues laterally over a distance of more than 10m at one end of the main body (Fig. 15). Maturity decreases with distance from the main body and locally up to 30cm in diameter angular red siltstone/clay clasts are present (Fig. 14b) giving thickening and thinning impression of the bed. Similar conglomerate bed is repeated again upwards with only one sandstone bed in between the conglomerates. This conglomerate bed pinches out laterally and equivalent sandstone bed have small troughs and horizontal lamination at the top. Overlying is a 50cm thick pebbly sandstone and conglomerate bed which consists of red siltstone/clay pebbles and clasts (Fig. 14d). Overlying 4m consists of horizontally laminated sandstone beds in the lower portion. Within these beds localized clasts of up to 20cm in diameter of carbonate cemented material (caliche) are present (Fig. 14e). Uppermost 3m of the sand-body consists of apparently massive and bioturbated sandstone.

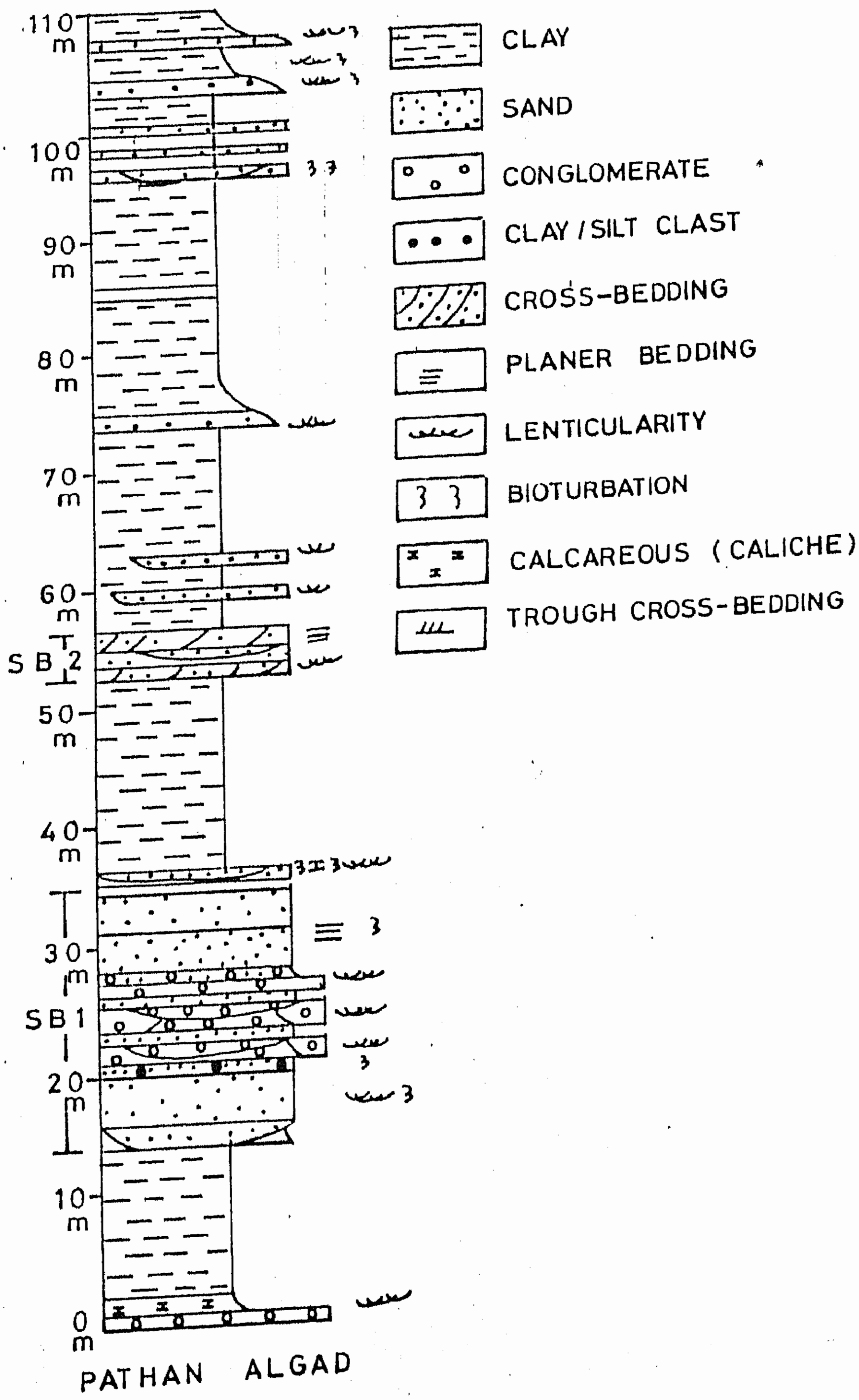


Fig. 13 Vertical lithologic column showing different lithofacies of the Murree Formation at the Pathan Algad Section.

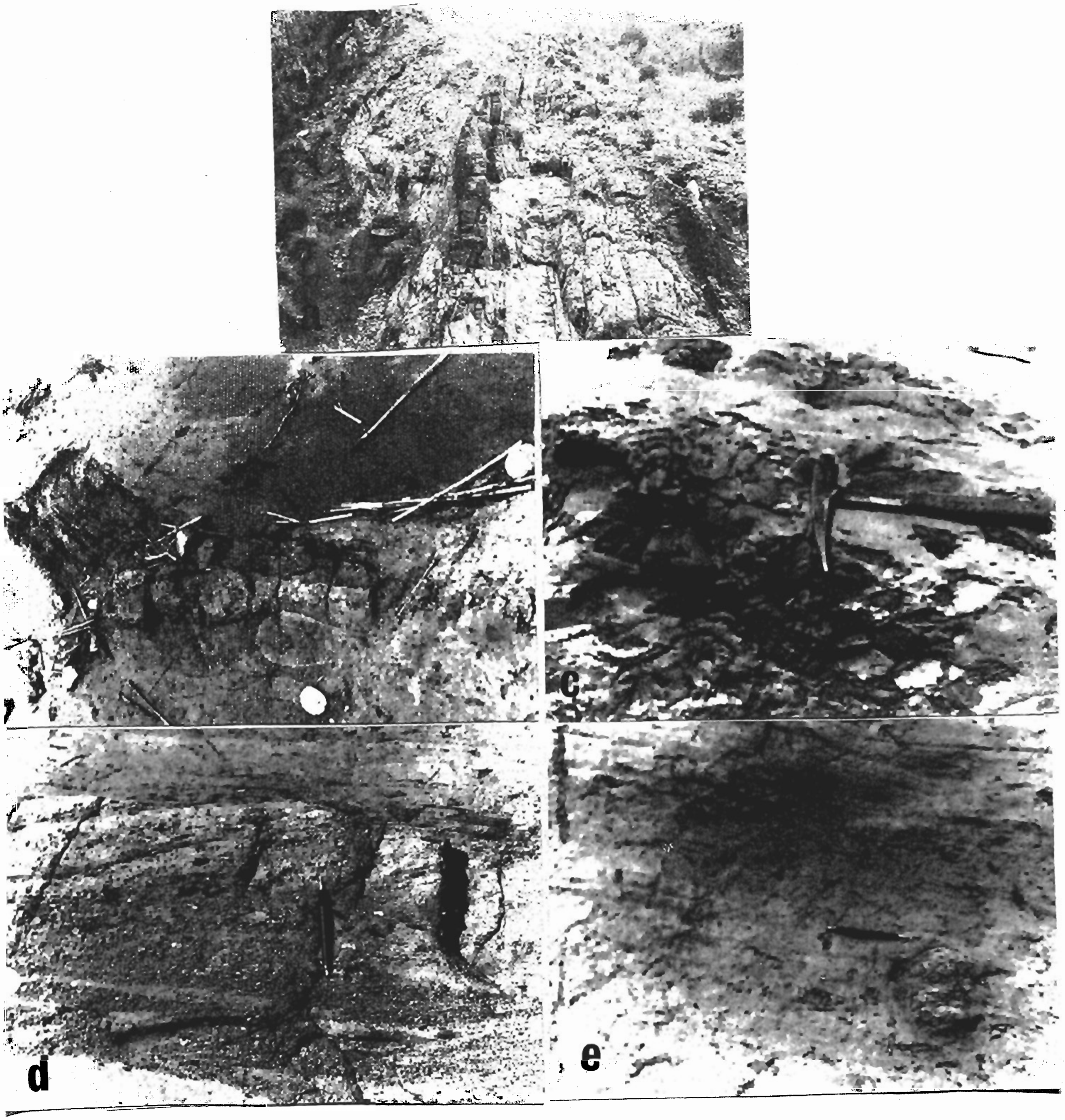


Fig. 14 Field photographs of sand body SB1. (a) Photograph showing complete thickness ~21-22m of SB1. Top is towards right. Note the scoured base and other features particularly dark colour conglomerate beds in lower half of the sand-body. (b) A part of the lateral extension of conglomerate beds showing angular upto 30cm in diameter silt/clay clasts. Pencil in 14cm long. (c) Red silt/clay clasts at base of a sandstone bed. Hammer is 33cm long. (d) Pebbly and conglomeratic bed with red silt/clay clasts. Upper part shows cross-bedding. (e) Calcareous siltstone (caliche) ball ~ 20cm in diameter embedded within a sandstone bed. Note also bioturbation in the bed.

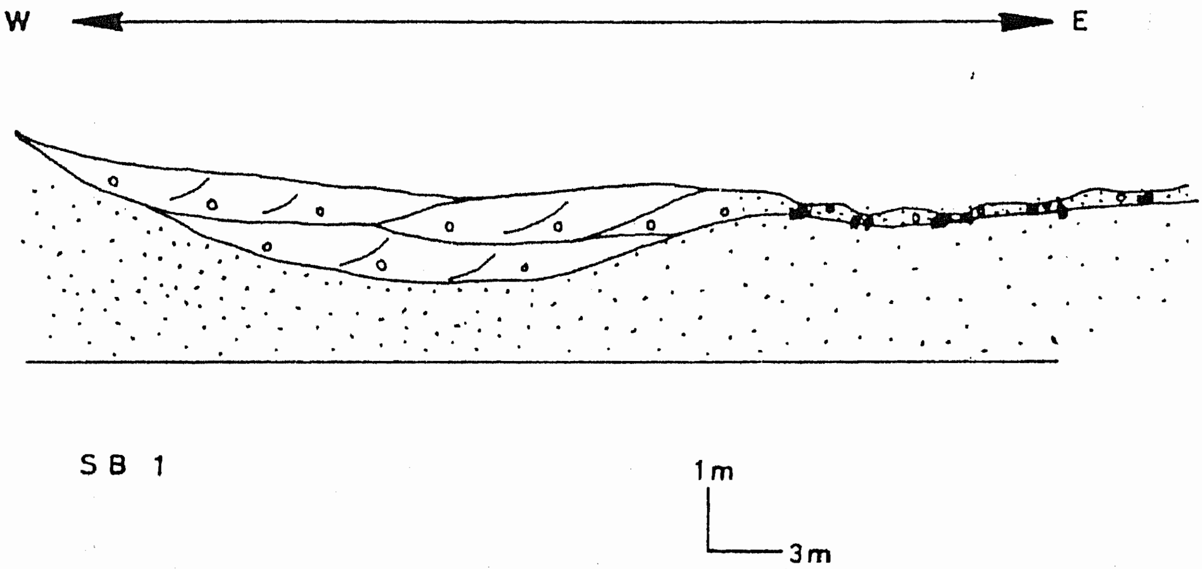


Fig. 15 Sketch of the mature conglomerate horizon in SB1 showing more clearly its lateral tapering.

The second major sand-body SB2 is at 50m level from the base. The sandstone beds are sharply and erosively based. On eastern end of the exposure the sand body is 4m thick (Fig. 16a). The middle 2m of the unit consists of sandstone beds with internal horizontal lamination. Both the basal and the topmost sandstone beds are, however, internally cross-bedded. The basal bed locally consists of low angle cross-bedding (Fig. 16a).

Tracing westward at a distance of 15m the same unit is only 2m thick (Fig. 17). Basal two thirds are made up of beautifully preserved megaripples with vertical thickness up to 60cm each and lateral extent of around 3m each. Upper one third is made up of superimposed small ripples cross-lamination with foreset thickness up to 8cm (Fig. 16b). 1 to 3cm in diameter red clay

pebbles are scattered all through the unit. Further 10m westward this sandstone unit looses its cohesiveness as a single sand-body but instead sandstone and clay beds alternate(Figs. 16c, 16d, 17). The sandstone is gradually replaced by red clay further westward.

Beside these major sand-bodies, the red clays make a considerable portion of the formation. Above SB2 a thick clay horizon consists of interbeds of 3 to 20cm thick sandstone beds in the lower portion (Figs. 16c & 16d). At 74m level from the base 19m thick clay unit consists of one 40cm thick calcareous clay zone (semicaliche) in its middle portion. The topmost 7m of the formation consist of two fining upward units. The upper unit grades from sandstone up into siltstone and then into red clay.

INTERPRETATION

The lithofacies in the Murree Formation as described above are similar to those which have been previously observed in many fluviatile deposits (e.g. Stewart, 1981; Walker and Cant, 1984; Miall, 1985). The lithofacies association, cyclic sedimentation, fining upward cycles and coarse to fine sediments ratio collectively suggests that the sediments of the Murree Formation were deposited by meandering streams (Fig. 19)(c.f. Friend, 1978).

Paleochannel studies of the Murree Formation suggests it generally to be the result of mixed-load channel setting (c.f. Galloway, 1985). Nevertheless, in lower half of the formation the tendency is towards bedload channel and in the upper half towards suspended-load channel.

Base of SB1 makes the initiation of a new river course in previous flood plain area and, therefore, a major shift in the river channel. Initially, as suggested by the small lateral extent of the basal sandstone beds, the river was mostly restricted to a narrow channel with slight lateral shifts from time to time. However, upwards within the sand-body the channel became more wide as attested by more lateral persistence of the beds. This is further supported by the presence of silt and clay clasts at base of beds which were derived either by bank collapse, erosion of the outer bank margin, abandoned channel or flood plain deposits. This simply indicates more freedom in water flow (Arche, 1983; Collinson, 1986).

The mature lm conglomerate horizon was developed during more than normal flood conditions which eroded sediments from the flood plain area and incorporated them as a stream load. There was either a shift in a channel direction which eroded parts of the previously deposited channel sand or alternatively another channel was entering obliquely into the main channel which deposited these conglomerates. The possibility of a chute channel cannot be ignored in which flow was channelized and one flank of the channel was well preserved. The chute bar deposits typically develop at top of point bar deposits (Galloway, 1985).

Overlying sandstones with horizontal lamination were deposited in shallow and broad channels in which upper flow regime conditions prevailed. Uppermost part of SB1 consists of massive looking sandstone beds in which the original structures might have got destroyed by bioturbation or were never developed due to rapid sediment dumping from high energy flows (Fielding, 1986) at top of point bar. Caliche bed at top of this sand-body suggests the long areal exposure, therefore, abandonment of the channel and major shift in stream course and termination of SB1 deposition.

Limited exposure of SB2 shows great lateral variations in thickness, internal sedimentary structures and lithology. At the eastern extremity, where the sand-body is 4m thick, the basal 1m sandstone with siltstone and red clay rounded clasts at base as channel lag was deposited in the main channel. The middle 2m sand with horizontal lamination and which sharply overlies the underlying channelized sand (Fig. 18a) was either deposited in a shallow channel or it may represent part of a point bar. The horizontal lamination results where the water depth is shallow and velocity is comparatively high and upper flow regime conditions prevail (Stewart, 1981; Allen, 1984). Topmost 1m with megarippled cross-lamination is interpreted as middle to upper part of a point bar.

About 10m westward the sand-body decreases in thickness to 2m. The basal channel bed consists of flood plain reworked sediments as lag at base and pinches out laterally. Overlying sand beds with megaripple cross-bedding overlain at top by small scale climbing ripple cross-lamination were formed at top of the point bar. A short distance further westward the sand-body fizzles out as a coherent unit and instead is represented by interbedded sandstone and shale beds. This facies represents deposits of either one or combination of the three mechanisms; one in the small side channel on the other side of the bar, two crevasse-flood plain sediments and three levee deposits (Plint, 1983).

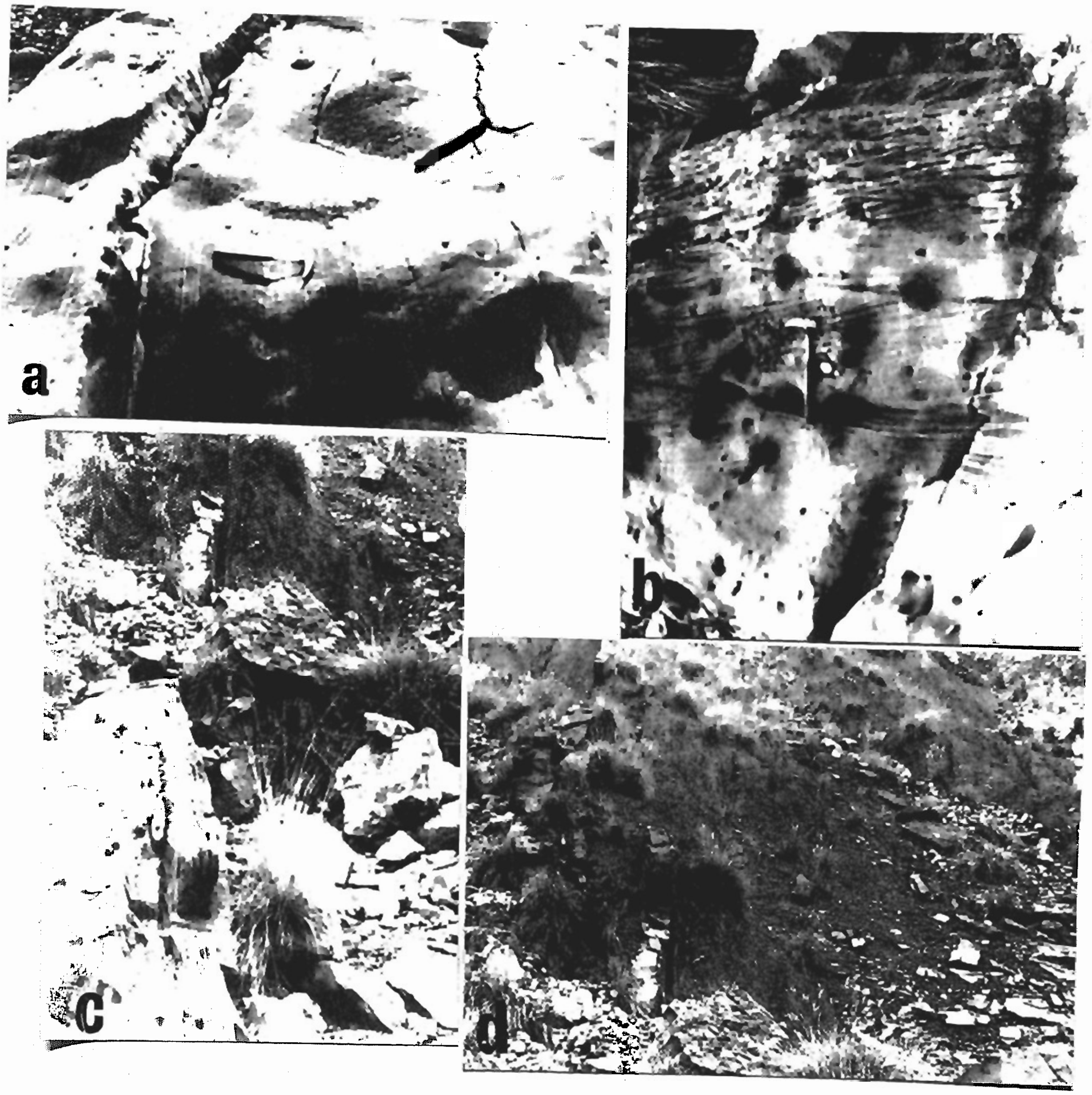


Fig. 16 Sand body SB2 at Pathan Algad (a) Eastern part of SB1 with lower bed low angle lamination and cross-lamination. The middle part with hammer shows horizontal lamination. Hammer is 33cm long. (b) Laterally middle zone of the sand-body. Base of the basal bed consists of silt/clay clasts and the overlying sand beds consists of cross-lamination mainly of megaripples and the top consists of small scale ripple lamination. (c) West of (b), the sand body thins out and changes to interbedded sandstone and red clay facies. (d) Further west of (c) showing more clearly interbedded sandstone and red clay facies.

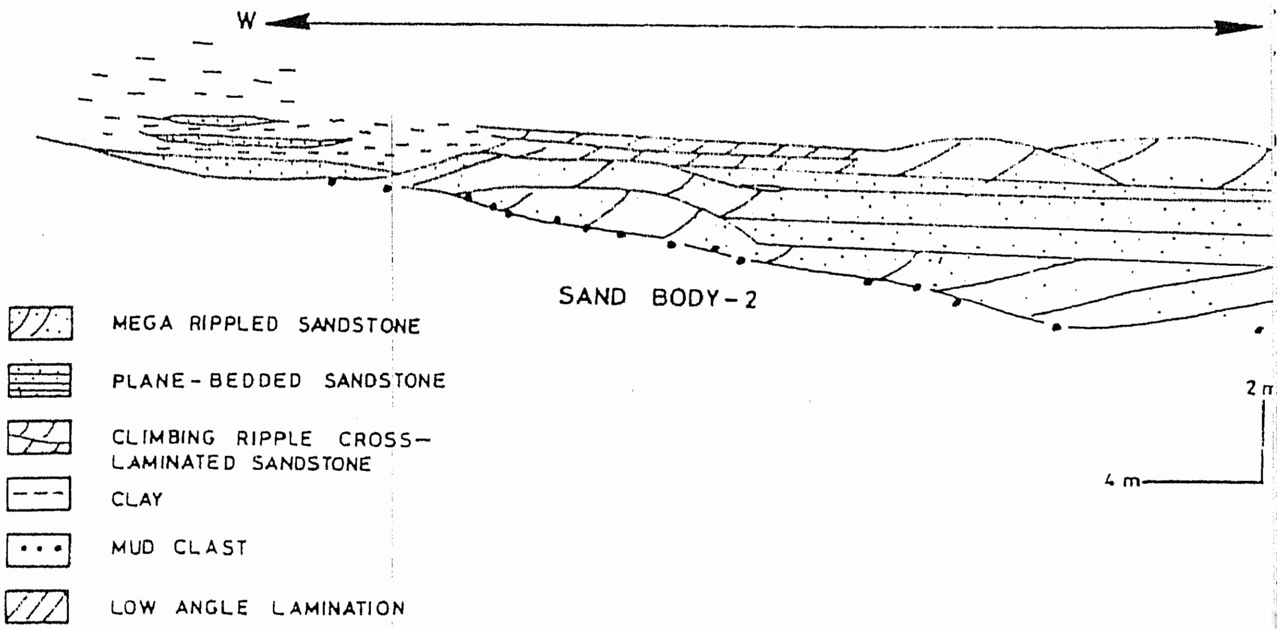


Fig. 17 Field sketch of sand-body SB2.

From the above discussion it could be concluded that the sand-body SB2 shows gradation from main channel in the east to either the bar and small side channel or crevasse or levee to flood plain in the west. Therefore it is suggested that the main channel existed eastward and as a result this sand-body might become more thick further east due to superimposition of channel sands.

Upper 7m of the sequence displays two fining-up cycles. Fine grain size and apparent massiveness of these beds does not qualify them as classical channel sands but may in fact be either left-overs of point bars or the crevasse splays or levee deposits within the flood plains by sheet like flood flow. Although any one of these processes may be involved, gradational grain size change in these cycles is more supportive of crevasse splay mechanism.

The red clays in fluviatile environments are traditionally interpreted as flood plain deposits (Reineck & Singh, 1980). During flood conditions in rivers the existing channel may not be able to hold the flow of water resulting in the overflow out of the channel. As flood subsides, the competency of water in the flood plain area decreases leading to complete stoppage in flow. This results in deposition of fine-grained sediments such as siltstones and clays. The clay deposition occurs out of suspension in standing water. Thick clay units suggest that the river must have stabilized in one position on the flood plains for longer times or that the river was more prone to flooding due to its maturity (Moody-Staurt, 1966; Harms et al., 1975).

2.4 COMPARISON BETWEEN THE EXPOSURES OF THREE SECTIONS

The Murree Formation in northern Kohat and Potwar is more thick than in southern Kohat at Pathan Algad (Fig 19). For instance at stratotype (Figs. 5) it is more than 500m thick and in northeastern Kohat at Ghorzai (Figs. 9) it is 270-300m thick. At stratotype basal unit consists of conglomerate and sandstone and is 62m thick. Here sand to clay ratio in lower levels is approximately 85:15 and changes roughly to 10:90 in upper levels of the formation (Fig. 5). At Pathan Algad sand to clay ratio does not change so drastically but does change from 40:50 in lower levels to roughly 30:70 in upper levels (Figs. 13). At both these exposures, prominent sand units lie in lower half of the formation while at Ghorzai in northeastern Kohat the sandstone and clay units are similar at all levels of the formation and sand to clay ratio is almost same around 45:55 (Fig. 9).

As stated earlier major sand-bodies lie towards the base at stratotype and at Pathan Algad . The same river could not have flowed at the same time in two widely apart east-west parallel locations specially when flow was generally from north to south. This suggests that either there was a considerable time gap between strata of the Murree Formation at these localities or alternatively

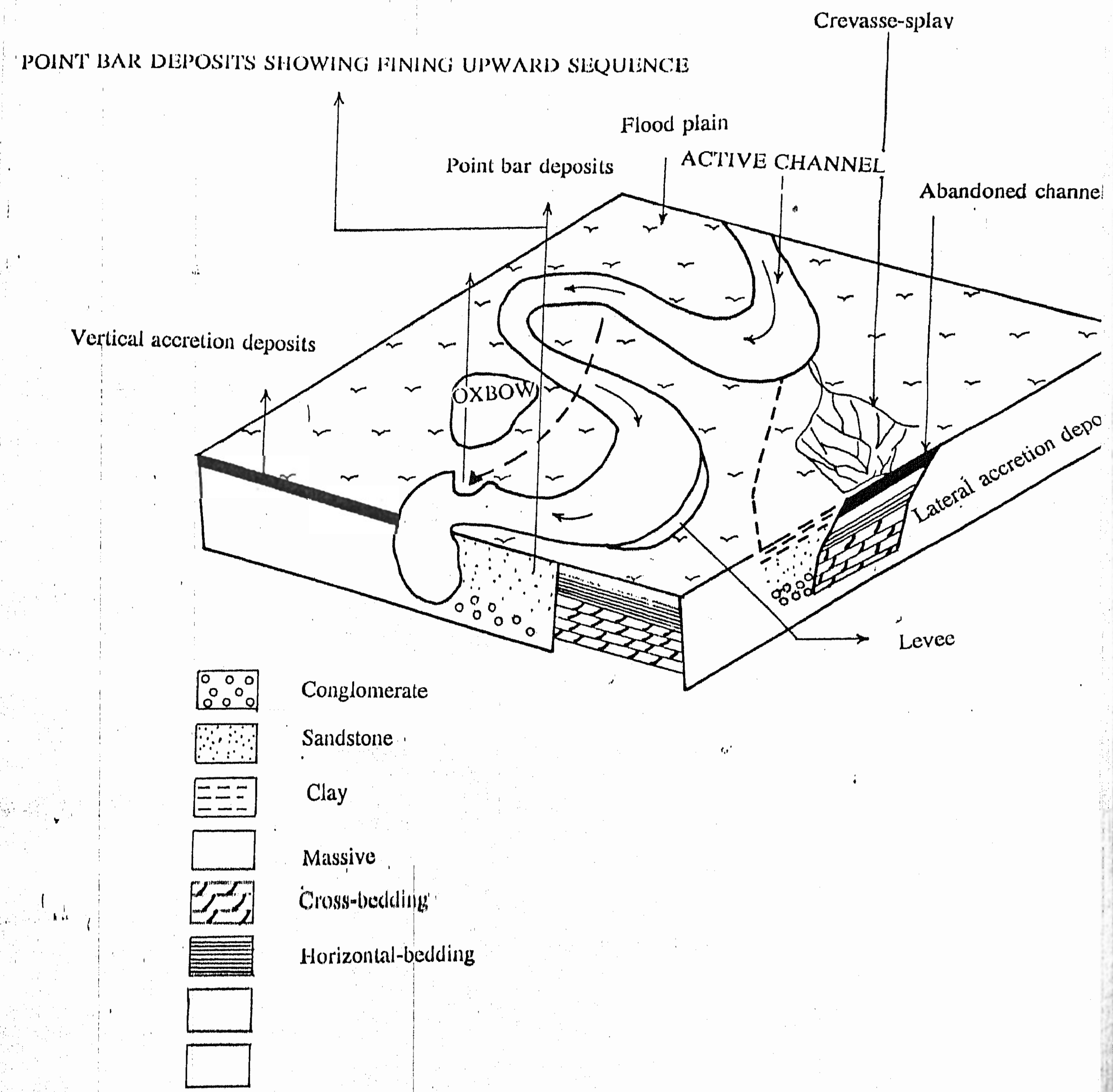


Fig. 18 Meandering river model showing channel shape and related typical deposits. (modified from Allen, 1964, 1970b).

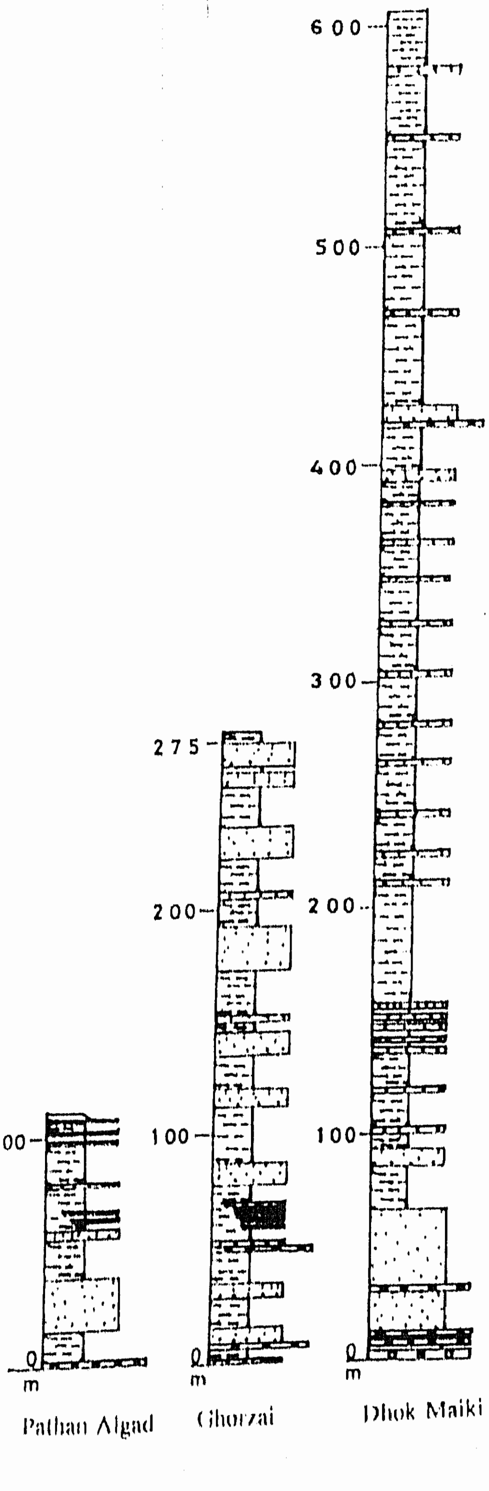


Fig. 19 Lithologic columns of the Murree Formation at three different localities.

they were deposited by different streams or some combination of both. The basal strata at stratotype which appears to represent the initial river path could, therefore, be older than the basal part of the exposure at Pathan Algad.

Initially during deposition of the basal thick sand-body at stratotype, the absence of intervening shale suggests that either subsidence rate was low or fine material was not available from the source. During deposition of the upper half of the formation, however, the subsidence rate was invariably high as is suggested by the thickness as well as abundance of fine-grained material in upper levels.

The Pathan Algad area on the other hand possibly was on the margin of the Murree river system and therefore, river flowed here occasionally only relatively for a shortwhile and avulsed again towards east. Ghorzai area experienced repeated river passage and repeatedly was acting as flood plain area of the Murree river, consequently, developing cyclic sand-clay units.

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CHAPTER 3

LITHOFACIES OF THE MURREE FORMATION

The Murree Formation is composed of clastic sediments, mainly clay, sandstone and conglomerate. The sediments show great vertical and lateral facies variations. The purpose of this chapter is to provide detailed description and interpretation of the lithofacies of the Murree Formation, their correlation and distribution, and cyclicity of sedimentary sequences. Each cycle starts with the basal conglomerate or sandstone and grades upward into fine clays (Figs. 5, 9 and 13).

The term lithofacies is restricted to the rock assemblage according to the color, bedding, composition, texture, fossils, sedimentary and biogenic structures. The following terminology is basically of Miall (1978) and has been modified where necessary.

Lithofacies	Gmt	Trough cross-bedded/massive conglomerate
Lithofacies	Gtp	Trough/planar cross-bedded sandstone
Lithofacies	Shl	Low angle to plane-bedded sandstone
Lithofacies	Sr	Rippled sandstone
Lithofacies	Fl	Interbedded sandstone and clay facies
Lithofacies	Fc	Massive red clays

3.1 Facies Gmt

Description

This facies makes the base of the formation at Dhok Maiki; the stratotype. The conglomerate beds are varied in internal arrangement and are cross-bedded, megarippled, plane-bedded and massive (Fig. 8b). Laterally most of the conglomerate is lenticular and occasionally continuous on outcrop scale. Bed thickness ranges from 10cm to 1m . The conglomerates are texturally immature, matrix supported, occasionally clast supported and have erosive bases. The basal conglomerate at the stratotype described as Fatehjang member (Shah, 1977) has sandy matrix, having pebbles up to 2cm in diameter. The conglomerate consists of fossils, pieces of silicified wood, and some fish bones (Fatmi, 1973).

At Pathan Algad the conglomerate beds are up to 40cm thick. Red siltstone or clay clasts up to 20cm in diameter are concentrated at the base of some beds (Fig. 14b). Though the clasts are randomly distributed but largely normal grading is present. Three largely pinching composite conglomerate beds, which combinely are around 50cm thick, makes the base of the formation at Pathan Algad.

At Ghorzai in the basal portion of the formation the conglomerates are lenticular, cross-bedded and bioturbated. The cross-bedding is trough shaped, and beds thin out laterally within a distance of 60m. It consists of red clay as well as extrabasinal clasts up to 1.5cm in diameter. Generally the clasts are embedded in the sandy matrix.

Generally the conglomerates are present at the base of a fining upward cycle, forming units from 2-3m in thickness, which overlie a planar or uneven erosional surface with local small scours. They are composed of intraformational clasts of mainly sandstone, siltstone/clay, and extraformational clasts as well at certain localities. Large angular to sub-rounded clay clasts in the form of mud balls are also present.

INTERPRETATION

The conglomerates commonly associated with the scoured surfaces are generally considered to be channel floor lags on the river beds. Fielding (1986) suggests clast supported conglomerates as channel floor lags and matrix supported as lag deposits. Within the main high energy channel the finer material does not get settled and as a result clast supported conglomerates forms. Nevertheless, in areas within the domain of the channel where the water flows only during floods, matrix supported conglomerates forms. The fine-grained material fills the voids with the subsidence of flood as a result of continuous decrease in energy level. Depending upon the availability of the clast and the competency of flow the conglomerate beds are either continuous or lenticular. The Fatehjang member at the stratotype consists clasts that are reworked from the underlying Eocene Chorgali Formation (Shah, 1977).

Large silt/clay clast concentration at the base of the conglomerate beds probably originated from the bank collapse and erosion of clay layers from previously deposited flood plain deposits. Angular clasts indicate a proximal source and rounded clasts may have come from distal areas. The amalgamation of the conglomerate beds suggests recurrence of high energy events, each phase eroding upper parts of the previously deposited sediments. The eroded portion was most likely relatively fine-grained that could have been deposited during low flow conditions. Local pinching of interbedded sand sheets may also be responsible for multistorey conglomerate formation (Mader, 1985).

The intraformational conglomerates do not show any break in sedimentation rather they show the occurrence of high energy conditions. These conglomerates results from the bank collapse along the meander bend or alternatively by the erosion of the underlying silt/clay beds. They are common in the lower reaches of the river systems, concentrated at the base of the point bars (Bluck, 1971). The intraformational conglomerates may also consist the eroded and reworked overbank fines during lateral channel shifts (Mader, 1985). Mader further suggests that thin layers of intraformational conglomerates interrelated into sandy or extraformational gravelly sequences, as are present in Ghorzai section, reflect discrete phases of channel shifts alternating with periods of water course stability and only negligible lateral erosion.

3.2 Facies Gtp

Description

This lithofacies consists of grayish brown sandstone, which is coarse to medium-grained, and occasionally fine-grained. The facies generally is trough cross-bedded, rarely planar cross-bedded. The set thickness is up to 25cm.The individual beds are generally up to 40cm thick, rarely up to 1m thick. Trough and planar cross-sets are generally segregated except at stratotype in sand-body DM4, where they are interbedded (Fig. 8b). The sandstone units are up to 7m thick.

At stratotype both trough and planar cross-bedded sandstones are present (Figs. 7a and 8b). Troughs are up to 1.5m wide and 20cm thick (Figs. 7aand 8b). The planar cross-beds set thickness is up to 12cm and dip is up to 30° (Fig. 8b). At Ghorzai, troughs are scooped shaped, having thickness up to 25cm. Individual beds range in thickness from 2 to 25cm, sometimes more (Fig. 12c). At Pathan Algad the troughs are up to 20cm thick and 1m wide with individual bed thickness 15cm or more. This facies have sharp to erosive bases and flat to slightly undulating top, in addition to the gravel embedded lenses at Pathan Algad (Fig. 14d).

This facies is found generally towards the base of the sand-bodies. Foresets generally have tangential bases in case of trough cross-bedding and angular bases in planar cross-bedded sandstones.

INTERPRETATION

Trough and planar cross-bedded sandstones, usually in sets of 10-25cm thick are the principal facies of point bar sequences. Trough cross-bedded sandstone of facies (stp) was probably deposited as the river moved laterally by eroding the concave bank and depositing them on the convex side of the channel. Harms and Fahenstock (1965) suggested the flow phenomenon from upper part of lower flow regime to the lower part of the lower flow regime. The trough cross-bedded sandstones overlying conglomerates, are deposited in the lower point bar or mid point bar deposits. Similar interpretations are made previously by many workers (e.g. Allen, 1970a; Levey, 1978; Stewart, 1981; Plint, 1983). Jackson (1976) and Levey (1978) described trough cross-bedding as produced by the aggradation of linguoid to strongly sinuous current ripples or three dimensional dunes, where as trough cross-laminations are produced by migration of linguoid ripples on the point bars.

The cross-lamination that is more generally developed towards the upper portions of the sand-bodies was possibly produced in the shallower part of flow on top of point bar laterally away from the center of the main channel (Walker and Cant, 1984). Here the rippled bedform would produce ripple cross-lamination or trough cross-lamination. This process of preservation is due to lateral and downstream accretion of point bar where channel floor dunes may be driven diagonally on the lower part of the point bar to accrete laterally on top of the channel floor lag. Planar cross-bedding, which is atwo dimensional bedform in the sand-body DM4 at stratotype was most likely produced by the migration of straight crested dunes.

Grouped cross-sets, as are found in Pathan Algad section and at stratotype, represent water deep enough to allow deposition as cosets since isolated sets develops in shallow water depths where superimposition is not likely (Rust, 1984).

3.3 Lithofacies Shl

Description

This facies, which is present in all the sections, consists of medium-grained sandstone that is slightly finer than those forming trough cross-bedding of facies Stp. The individual beds are up to 34-40cm thick and are internally horizontally bedded (Fig. 10c). The horizontal-bedding is sometimes converted into low angle plane-bedding (Fig. 16a). The plane-beds are traceable for several meters. Low angle plane-bedding is transitional both vertically and horizontally to plane-bedding and dips at an angle less than 10° to the horizontal (Fig. 16a). This facies make units up to 3m thick and locally these are laterally traceable for several meters. This facies usually occurs in the upper portions of the sand-bodies (Fig. 16b). Generally the beds are composite in nature but at some localities intervening shale is present in between the sandstone beds. At places bioturbation is also observed (Fig. 20).

INTERPRETATION

The plane-bed formation results either when the flow is too fast and shallow depth to develop upper flow regime conditions. In the standing water the sedimentation takes place out of suspension which mostly results in deposition of clays. The facies Shl was, therefore, deposited under upper flow regime conditions. The deposition of such beds is previously reported both from within and also from top of the point bars (McKee et al., 1967; Allen, 1982; Walker and Cant, 1984). In situations where plane-beds are present in between the megaripples and small ripples, they may have been formed due to decrease in velocity at dying flood stages (Reineck and Singh, 1980). Such a scenario can also be explained by the fluctuations in the flow velocity.

Plane-beds are present in both steady unidirectional flows and symmetrical oscillatory flows (Harms et al., 1982). Paola et al. (1989) viewed that the lateral continuity of the parallel lamination and low angle plane-bedded sandstone is due to subturbulent fluctuations caused by migration of bedforms. These bedforms have amplitude of only few grains wavelength from decimeters up to a meter and migration speed of several mms-1.

Low angle cross-bedding which is present in almost all the studied sections is formed either due to migration of sandwaves or is produced by shallow, high velociety flow into broad scours that are too shallow to form cross-strata. These low angle plane-bedded sandstones appear very much similar to the ones mentioned by Coleman (1969).

3.4 Lithofacies Sr

Description

This facies is present at all the sections. The facies consists of sandstone beds with small scale ripples which form cosets up to a few cm thick. At Pathan Algad section both the small scale megaripples and small climbing ripple-lamination, with foreset thickness up to 8cm, are present (Fig. 16b). At stratotype rippled facies is present at top of sand-body DM4 (Fig. 8c). At Ghorzai section both climbing and non-climbing ripple cross-lamination is present. Sand-bodies which occur within this facies usually show very limited basal erosion. Major channel features and lateral accretion surfaces are not present. Sandstone units are 1-2m thick, individual beds range in thickness from 10 cm to 25 cm. These sandstone beds show lateral pinching and fines upward into flood plain deposits.

INTERPRETATION

This facies was formed under relatively low flow velocity which more typically develops in the shallower parts of the channels and on the exposed surface of the point bars. Friedman and Sanders (1978) and Plint (1983) have also reported such deposits on the exposed surface of the point bars. At places sheet like nature of the deposits and the lack of erosional surfaces is

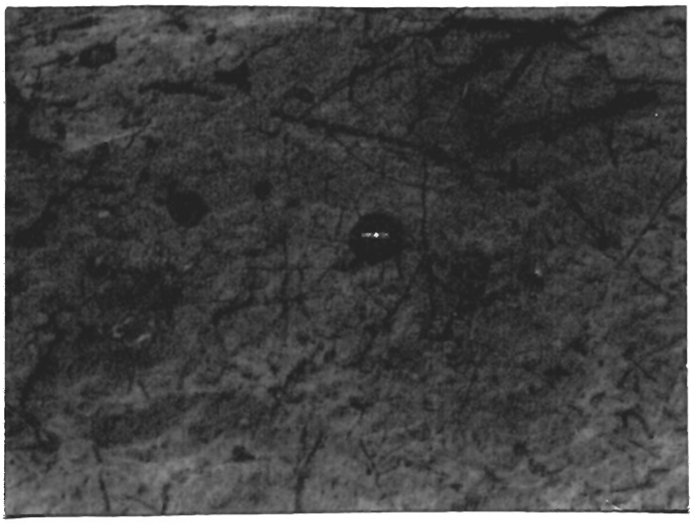

Fig. 20 Organic marking in a sandstone bed.

suggestive of accretion on broad, flat and non-channelized plain (Graham, 1983). Transition from horizontal-bedding to ripple-bedding results from late stage decrease in flow velocities (Leeder, 1973). Small scale cross-lamination located near the top of the point bar, as are present in the upper portions of sand-body SB2 at Pathan Algad, was probably produced by migrating ripple trains formed under lower flow regime conditions (Simons et al., 1965).

3.5 Lithofacies F1

Description

This facies consists of clay with interbeds of sandstone. siltstone. The sandstone beds generally pinchout laterally over a distance of a few to tens of meters (Fig. 16d). As a whole the clay makes thicker units than sandstones. The sandstone is medium- to fine-grained. They are sharp and irregularly based and are mostly up to 20cm thick rarely more. The tops of some of the sandstone beds are rippled. This facies most oftenly lies at the top of the sand-bodies and consists of comparatively finer grained sandstone, massive clay and at places siltstone. The sandstones sometimes show small scale cross-lamination and are locally extensively bioturbated. A complete transition from sandstone to siltstone to clay is observed at Pathan Algad section (Fig. 16d). At stratotype and at Ghorzai sections thin sandstone beds up to 10cm thick, which pinchout laterally over a distance of 20-30m, are interbedded with red massive clays (Fig. 11c).

This facies forms units which are laterally extensive but vertical thickness is less than 20m.

INTERPRETATION

Thin bedded sand and clay are the result of floods and are the deposits of flood basins, levee (Ray, 1976) or crevasse splays (Qureshi and Tanoli, 1992). This facies is interpreted as a levee accumulation at the margin of the channel, which are comparable to the levee deposits of Stewart (1981) and Plint (1983). The sands are transported in the form of sheet flows over channel banks during flood stages and gets deposited as thin layers on the levee flanks. These levees slope away from the main channel into the flood plain areas and are developed on the concave erosional bank, and are submerged only during the highest floods. The transition from sandstone to clay, as observed in the Pathan Algad section, most probably represents the longitudinal section along the levee or a crevasse course. When the flood water overtops the channel bank there is a fall-off in the level of turbulence and suspended sediment is deposited, the coarser sand and silts close to the channel, the finer sediments farther away on the flood plain. The other possibility for these interbedded sandstones and clay could be the result of the development of crevasse splays. The crevasse splay deposits are usually thin, on a scale of only few tens of centimeters and occasionally 1m thick. They are generally sharply based and wedge out laterally over a short distance.

Third possibility for the formation of this facies is that it was deposited in small channels which were crevassed within a large channel. After the flood receded the flow was confined in these small channels, which resulted in the deposition of the interbedded sandstone, siltstone and clay.

3.6 Lithofacies Fc

Description

Red massive clays have substantially higher representation than any of the other facies in all the sections. Traces of lamination in the clay are scarce. Massive clays occur as thick sequences both above and below the sand-bodies (Figs. 11c, 14a and 16). They are generally red and brown in color and contain little internal visible structures. Calcareous horizons (caliche) occur within red clays (Figs. 14e and 21). Thickest units, up to 40m thick, of this facies are present at the stratotype. This facies either directly overlies, with a sharp base, above the sand-bodies or gradually passes through interbedded sandstone and red clay horizon (Figs. 16d).

INTERPRETATION

Red massive clay facies is interpreted as flood plain deposits as a result of fallout from suspension after flood subsidence (Reineck and Singh, 1980). After the flood water overtops the bank, it causes uplifting of the flood plain by the process known as vertical accretion (Walker and Cant, 1984). Thick overbank fines are favored by large lateral movement of the channel, if the spreading of these fines (red clays) occur at the time of flooding (Friend, 1978). Deposition of these clays is common in interchannel areas as well which receive sediments during floods. The red color of the clay is due to subaerial exposure and oxidation conditions (Collinson, 1986). Thick clay deposits most likely are the result of high input of fine-grained sediments which is favored by channel consistency in space and higher subsidence rate in the flood plain area.

The caliche beds were formed in semi-arid to arid climate in soils with low organic content which results in increase of pH value. This causes precipitation of $CaCo_3$ and as a result caliche is formed. The caliche formation is favored in places where for a certain period of time there is negligible sedimentation (Reineck and Singh, 1980).

3.7 LITHOFACIES ASSOCIATION

The strata of the Murree Formation consists of several lithofacies such as facies (Gmt), (stp), (Shl), (Sr), (Fl), and facies (Fc). These facies show different facies associations at different localities.

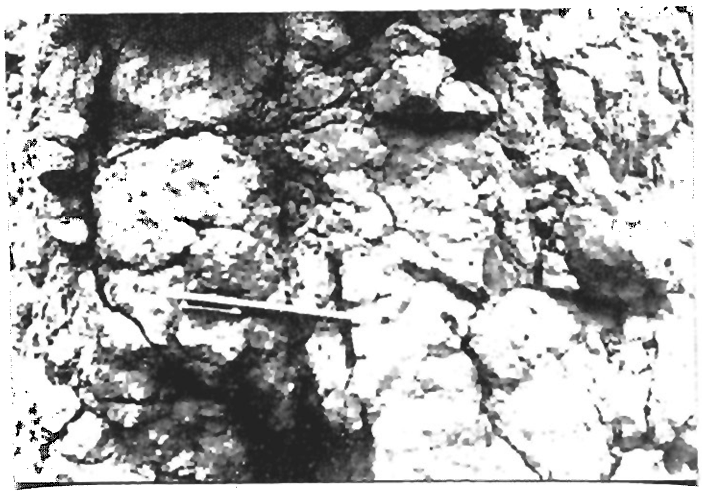

Fig. 21 A close view of a calcareous horizon below the Pencil.

Facies Gmt makes the base of the formation at the stratotype and at Pathan Algad. At the latter locality facies Gmt is directly overlain by facies Fc. Facies Gmt mostly makes the base of sand-bodies. However, it also interchanges with the facies Stp beds within the sand-bodies. In several instances the facies Stp makes the base of the sand-bodies.

Facies Stp is the most common of all the facies. At Ghorzai this facies makes the major portion of the sand-bodies. Except in sand-body SB1G and SB3G where it overlies facies Gmt, it generally overlies facies Fc. At stratotype, in the sand-bodies DM1, and DM4, this facies overlies facies Gmt and passes upward into facies Shl. In sand-body DM3 this facies overlies facies Fc and is overlain by facies Shl. In conclusion Facies Stp either overlies the facies Gmt or makes the basal part of the sand-bodies. Facies Shl which overlies the facies Stp mostly lies in the middle or upper portions of the sand-bodies.

Facies Sr, if present, overlies facies Shl in the upper portions of the sand-bodies as seen in sand-body SB2 in Pathan Algad. Facies Fl overlies the sand-bodies and act as transitional facies to facies Fc. Facies Fc is the uppermost facies of a fining-upward sequence. It either gradationally overlies the sequence via facies Fl or sharply overlies any of the other described facies in a sand-body.

The fining-upward sequences and the pattern of the lithofacies association suggest a meandering river for the strata of the Murree Formation at these sections. During deposition of the basal sandstone unit at stratotype subsidence rate was low, but the subsidence rate were high in the upper portions of the section. It is confirmed by the thick clay deposits in the upper portions. Ghorzai section experienced repeated river passage, on the other hand Pathan Algad area was on the margin of the Murree river system. Thick clay deposits of facies (Fc) suggest that the river must have stabilized in flood plains for a longer time.

CHAPTER 4

PROVENANCE OF THE MURREE FORMATION

Strata of the Rawalpindi Group are the result of collision between the Indian and the Eurasian plates (Powell, 1979: Tahirkheli et al., 1979). Rawalpindi Group has two formations: older Murree Formation and younger Kamlial Formation. The Murree Formation is composed of clay, sandstone and conglomerate with occasional siltstone. Age determined for this formation in the north is about 55 ma in the Hazara Kashmir Syntaxis (Bossart and Ottiger 1989) and early Miocene in the Kohat-Potwar area (Fatmi, 1973; Meissner et al., 1974 and Tahirkheli, 1982). This age difference in the north and south is due to southwestward migration of the Himalayan thrust front which also moved Murrees and Himalayan Foreland Basin to the southwest (Bossart & Ottiger, 1989). Sediments of the Murree Formation are widely spread from west of Peshawar over the Kohat-Potwar Province and Salt Range to the Hazara-Kashmir Syntaxis and from there to Jammu and the North Indian Plain (Fig. 1).

The present study was carried out at three different sections: stratotype at Dhok Maiki (lat 33°-25'N: long. 72°-35'E): Ghorzai (lat. 33° 31'N long 71° 44'E) and at Pathan Algad (lat 33°-17'20" N and long. 71° 27'E). Thirty thin sections from these different sections were prepared for the petrographic analysis.

At type locality the Murree Formation overlies unconformably the Chorgali Formation of Eocene age and at Ghorzai and at Pathan Algad it unconformably overlies the Kohat Formation of Eocene age.

Wynne (1874) called the present Murree Formation as Mari Group. In (1877) he assigned Miocene age for these rocks and described them as marine to continental in origin. Pinfold (1918) proposed the name Fatehjang member for the conglomeratic base of the Murree Group, this zone is exposed at type locality and consists of fish bones, pieces of silicified wood and is cross-bedded. He also described a time gap between Fatehjang member and underlying formations. Wadia (1926, 1931) accepted this idea for Kohat-Potwar Plateau but he described this passage from Mari Group and underlying formation as transitional in Hazara-Kashmir Syntaxis (Shah, 1977) and named these rocks as Murree Formation.

The aim of this study is to reconstruct the nature and the position of the source areas for the sandstone of the Murree Formation, about the uplifts and the evolution of the orogenic belts in the source area.

The sandstone of the Murree Formation is generally medium-grained and occasionally fine grained in the studied sections. The samples generally consist of quartz, feldspar, micas, cherts, opaques, lithic fragments, unidentified and accessory minerals. The brown and dark color of sandstone is mainly due to the concentration of opague minerals such as hematite and magnetite.

4.1 PETROGRAPHIC PROCEDURE

The petrographic studies are confined to the sandstone units of the Murree Formation. More than seventy samples were collected from three different measured sections namely type section at Dhok Maiki; Ghorzai section and Pathan Algad section of the Murree Formation. Thin sections were made of the samples of conglomerates and coarse-to-fine grained sandstone. Due to compositional and textural homogeneity and /or the fine grain size of the several thin sections, only thirty thin sections were considered as suitable for the petrographic analysis. Medium and coarse-grained sandstone are usually considered compositionally more representative of the source terrain than the fine-grained sandstone which could be deficient in certain minerals.

Point counting was done for each thin section. Between 136 to 390 grains were counted for each thin section depending mainly on the grain size. Both the horizontal and vertical runs were made during the grain counting study.

Dickinson and Suczek (1979), Dickinson et al., (1983), and Ingersoll and Suczek (1979) schemes of the grain division was applied. The percentage of each grain type for various thin sections is given in the modal composition charts (Tables 4.1, 4.2, and 4.3).

4.2 MINERALOGY

The dominant minerals, nature and additional information regarding the individual grains is explained here.

QUARTZ

It generally makes the predominant constituent of the sandstone in all the samples. Texturally it ranges from angular to subangular and subrounded. Straight and undulose extinction can be seen.

Both monocrystalline and polycrystalline varieties of quartz were present in the studied thin sections (Tabs. 4.1, 4.2, 4.3). Fine-grained sandstone generally without inclusions and consists of more monocrystalline quartz grains. Here quartz grains are angular to subrounded. Fractured grains of quartz may be filled by mica and in various thin section stretching in the quartz grain was also observed.

CHERT

It is in the form of polycrystalline quartz. It ranges from 1 to 8 percent (Tabs. 4.1, 4.2, 4.3). In some thin sections fibrous variety of quartz known as chalcedonic quartz is also present.

FELDSPAR

Feldspar is present in small amounts. It ranges from 1 to 6 percent (Tabs. 4.1, 4.2, 4.3). Plagioclase is generally higher in percentage than alkali feldspar. Due to sericitization proper recognition of some of the feldspar grains was difficult. Alkali feldspars are in the form of microcline, perthite and orthoclase. The grains are angular and devoid of inclusions. Albite type and combined carlsbad-albite twinning is seen in the plagioclase.

MICA GROUP

Both the muscovite and biotite variety is present in the samples collected.

Muscovite ranges from one to 16 percent. The stratotype and Ghorzai section has generally higher proportion of muscovite than Pathan Algad section. It is in the form of tabular crystals or in the form of aggregate of fine crystals. Extinction is usually parallel to the cleavage traces. Twinning is common which can be seen by differences in interference color and extinction angle. Biotite is brown, reddish brown and yellowish brown in thin sections and shows pleochroism in plane polarized light. It has strong absorption. At stratotype biotite is present in seven thin sections and shares up to 3 percent of overall mineral composition. At Ghorzai it is present in only three thin sections. In one of these thin sections it reaches up to 14 percent. At Pathan Algad it is present in only one thin section and reaches up to 15 percent of overall mineral composition. Scarcity of the biotite in this section is due to its alteration to chlorite by weathering.

LITHIC FRAGMENTS

Lithic fragments are one of the major components in most of the samples. Lithic fragments in thin sections are made up of quartz tectonite, quarts mica aggregate, quartz mica feldspar aggregate, quartz feldspar aggregate, Opaques and unidentified lithic fragments. The percentage of individual lithic fragments are given in (Tabs. 4.1, 4.2, 4.3).

Quartz mica tectonite and quartz mica aggregate are major lithic grain types in samples from the stratotype and Ghorzai.

Accessory minerals include chlorite, calcite, garnet, epidote, sericite, rutile and iron oxides. The cement is chiefly calcareous or siliceous.

OPAQUES

Opague minerals are found in all the samples in fair proportion. These opagues consist largely of hematite of diagenetic origin and to a lesser extent magnetite was also present in small proportions. Hematite is dark brown and black in color whereas magnetite is dark green. Hematite is in the form of grains but usually it is fine-grained and diagenetic.

TABLE: 4.1 Modal point count data in percent.

DHOK MAIKI SECTION

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Monocrystalline quartz	50	38	33	36	31	32	28	27	34	31
Polycrystalline quarts	23	27	43	38	36	44	57	35	38	54
Quartz Tectonite		2	1	1	3	1			4	1
Quartz Mica Tectonite		4	3	1	4	3	2	9	3	
Quartz Mica Aggregate	9		5	1	1	2		13		
Quartz Mica Feldspar Agg.		1	1				1			
Quartz Feldspar Agg.		1								
Muscovite	2	4	7	3	12	12	4	5	4	
Biotite	1	1			4	1	1	2	1	
Opague	10	6	4	3	2	2	5	5	10	5
Chert	1	3	2	1	1		1		2	5
Plagioclase	2	1		1	1	1	1	2	1	
Feldspar Undifferentiated		1			2			1		
Alkali Feldspar		2			1	1				
Chlorite					1					1
Calcite	1	2		1					1	
Epidote		2				1	1	1	1	1
Garnet									1	1
Sericite		1								
Iliminite		2								
Miscellaneous	1	2	1	4	2	1		1	2	3

TABLE: 4.2 Modal point count data in percent.

GHORZAI SECTION

	GR 1	GR 2	GR 3	GR 4	GR 5	GR 6	GR 7	GR 8	GR 9	GR 10	GR 11
Monocrystalline quartz	4	16	29	7	20	33	33	8	23	58	36
Polycrystalline quartz	71	64	44	59	70	46	49	79	54	18	28
Quartz Tectonite				4							
Quartz Mica Tectonite	5	2	2	7							
Quartz Mica Aggregate	4	1	2	3	2		1			1	1
Muscovite	7	7	7	11	5	2	1	1	4	3	16
Biotite			1	2							13
Opague	4	4	7	4	1	7	3	2	2	4	1
Chert	1	3	1		1	6	3	8	6	5	2
Plagioclase	1		1			1	1	1	6	5	2
Feldspar Undifferentiated	1										
Alkali Feldspar	2							1			1
Chlorite					1	1	1	1			
Calcite			2		3	6	1	1			
Epidote			1	1	1	1		1			1
Garnet						1	1				
Miscellaneous	2	1	3	3	1		1		2	3	

TABLE: 4.3 Modal point count data in percent.

PATHAN ALGAD SECTION

	PA 1	PA 2	PA 3	PA 4	PA 5	PA 6	PA 7	PA 8	PA 9
Monocrystalline quartz	45	47	57	16	56	19	28	70	60
Polycrystalline quartz	29	25	24	66	31	68	64	13	21
Quartz Mica Aggregate					1				
Muscovite		5		1	1	1	1		2
Biotite			15						
Opague	8	10	4	1	2	3	3	4	4
Chert	9	6		11	2	2	1	6	6
Plagioclase	2	2		3	1	5		4	3
Feldspar Undifferentiated				1					
Alkali Feldspar									1
Chlorite	1	4							
Calcite	1			1	4	1	1	1	1
Epidote		1			1	2	1		
Garnet		1		1					1
Sericite	1								
Iliminite		1			1	1	2	2	1
Miscellaneous									

Table: 4.4

GRAIN PARAMETERS

1:- Q = Qm + QP

Q = Total quartz grain

Qm = Monocrystalline quartz grain

Qp = Polycrystalline quartz grain + quartz mosaic grain + chert grains

2:- F= P + K + U

F = Total feldspar grain

P = Plagioclase feldspar grain

K = Potassium feldspar grain

U = Undifferentiated feldspar grain.

3:- L = Lvm +Lsm +M

L = Unstable lithic grains

Lvm = Volcanic hypabassal and metavolcanic lithic grains

Lsm = Sedimentary and metasedimentary Lithic grains

M = Opaques and miscellaneous

4: Lt = L + QP

TABLE: 4.5 End members of the ternary diagrams in percent, recalculated from Tables 4.1, 4.2 and 4.3.

DHOK MAIKI SECTION

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Q	77	77	84	78	81	89	91	63	79	91
F	2	5	0	1	5	2	2	3	1	0
L	21	18	16	21	14	9	8	34	20	9

GHORZAI SECTION

	GR 1	GR 2	GR 3	GR 4	GR 5	GR 6	GR 7	GR 8	GR 9	GR 10	GR 11
Q	82	89	83	76	96	91	93	96	89	86	93
F	2	2	1	0	0	1	1	2	7	5	4
L	16	9	16	24	4	8	6	2	4	9	3

PATHAN ALGAD SECTION

	PA 1	PA 2	PA 3	PA 4	PA 5	PA 6	PA 7	PA 8	PA 9
Q	90	87	95	95	96	92	97	92	92
F	2	2	0	4	3	5	0	4	4
L	8	11	5	1	1	3	3	4	4

Table: 4.6 End members of the ternary diagrams in percent, recalculated from Tables 4.1, 4.2 and 4.3.

DHOK MAIKI SECTION

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Qm	53	44	36	38	37	38	30	30	30	37
F	2	5	0	1	5	2	1	4	1	1
Lt	45	51	64	61	58	60	69	66	69	62

GHORZAI SECTION

	GR 1	GR 2	GR 3	GR 4	GR 5	GR 6	GR 7	GR 8	GR 9	GR 10	GR 11
Qm	4	17	32	8	21	35	36	8	24	61	50
F	2	3	1	0	0	2	2	2	8	6	5
Lt	94	80	67	92	79	63	62	90	68	33	45

PATHAN ALGAD SECTION

	PA 1	PA 2	PA 3	PA 4	PA 5	PA 6	PA 7	PA 8	PA 9
Qm	50	52	67	16	61	19	29	72	63
F	2	2	0	4	1	6	1	4	4
Lt	48	46	33	80	38	75	71	24	33

TABLE: 4.7 End members of the ternary diagrams in percent, recalculated from Tables 4.1, 4.2 and 4.3.

DHOK MAIKI SECTION

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Qp	64	65	75	49	76	83	88	59	68	87
Lvm	0	0	0	0	0	0	0	0	0	0
Lsm	31	35	25	51	24	17	12	41	32	13

GHORZAI SECTION

	GR 1	GR 2	GR 3	GR 4	GR 5	GR 6	GR 7	GR 8	GR 9	GR 10	GR 11
Qp	83	89	76	74	95	88	91	98	98	74	94
Lvm	0	0	0	0	0	0	0	0	0	0	0
Lsm	17	11	24	26	5	12	9	2	2	26	6

PATHAN ALGAD SECTION

	PA 1	PA 2	PA 3	PA 4	PA 5	PA 6	PA 7	PA 8	PA 9
Qp	83	74	86	98	92	96	96	83	87
Lvm	0	0	0	0	0	0	0	0	0
Lsm	17	26	14	2	8	4	4	17	13

TABLE: 4.8 End members of the ternary diagrams in percent, recalculated from Tables 4.1, 4.2 and 4.3.

DHOK MAIKI SECTION

	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Qm	96	97	100	95	97	97	97	93	97	100
P	4	3	0	5	3	3	3	7	3	0
K	0	0	0	0	0	0	0	0	0	0

GHORZAI SECTION

	GR 1	GR 2	GR 3	GR 4	GR 5	GR 6	GR 7	GR 8	GR 9	GR 10	GR 11
Qm	80	100	97	100	100	97	97	89	79	92	95
P	20	0	3	0	0	3	3	11	21	8	5
K	0	0	0	0	0	0	0	0	0	0	0

PATHAN ALGAD

	PA 1	PA 2	PA 3	PA 4	PA 5	PA 6	PA 7	PA 8	PA 9
Qm	96	96	100	84	98	79	100	95	95
P	4	4	0	16	2	21	0	5	5
K	0	0	0	0	0	0	0	0	0

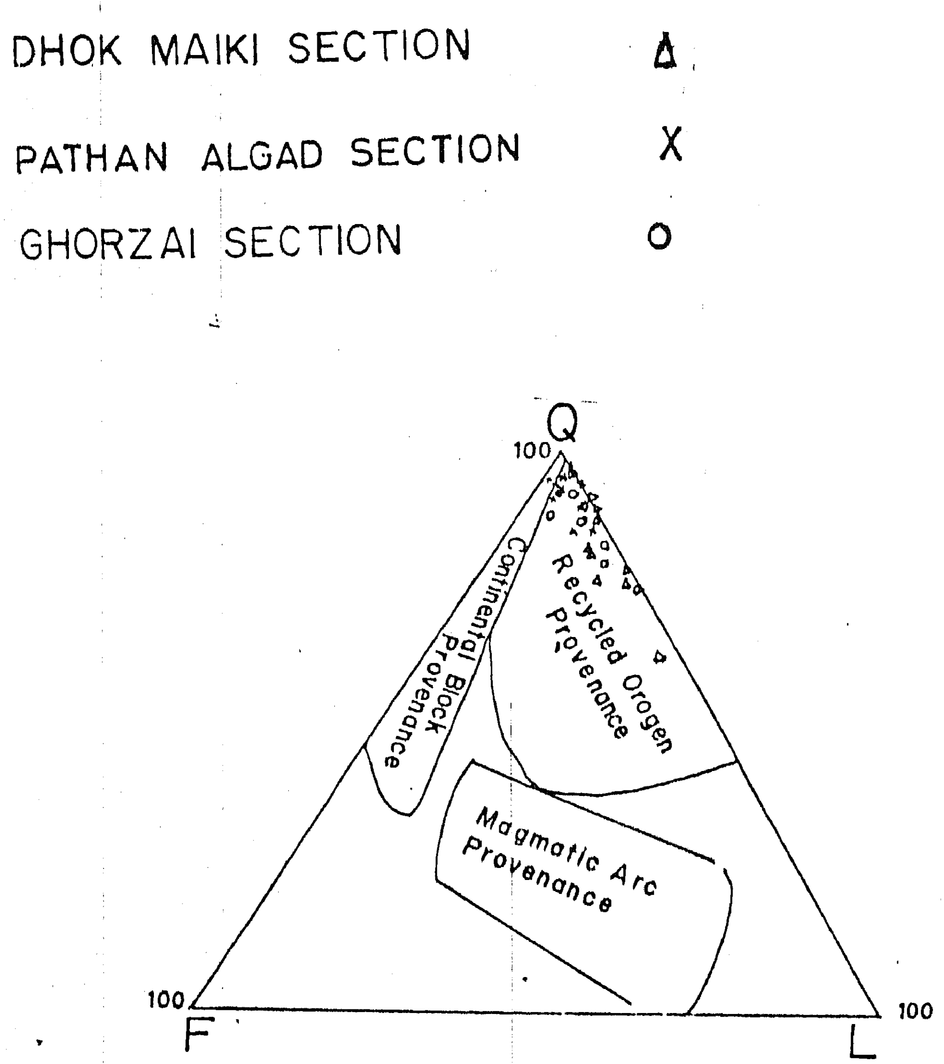

Fig. 22 Triangular QFL plot of modal analysis for the sandstones of the Murree Formation. The delineated provenance fields are after (Dickinson and Suczek 1979).

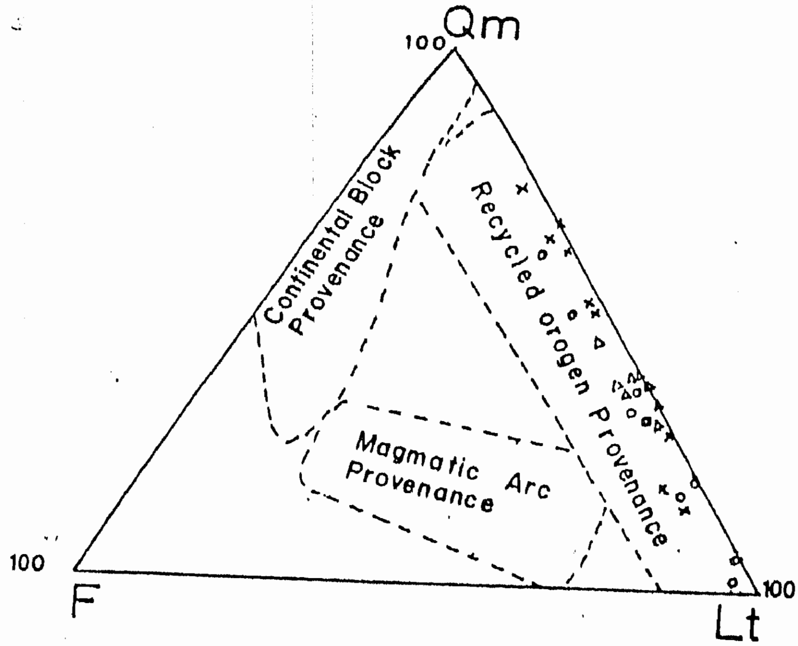

Fig. 23 Triangular QmFLT plot of modal analysis for the sandstones of the Murree Formation derived from different types of provenances. (after Dickinson and Suczek, 1979).

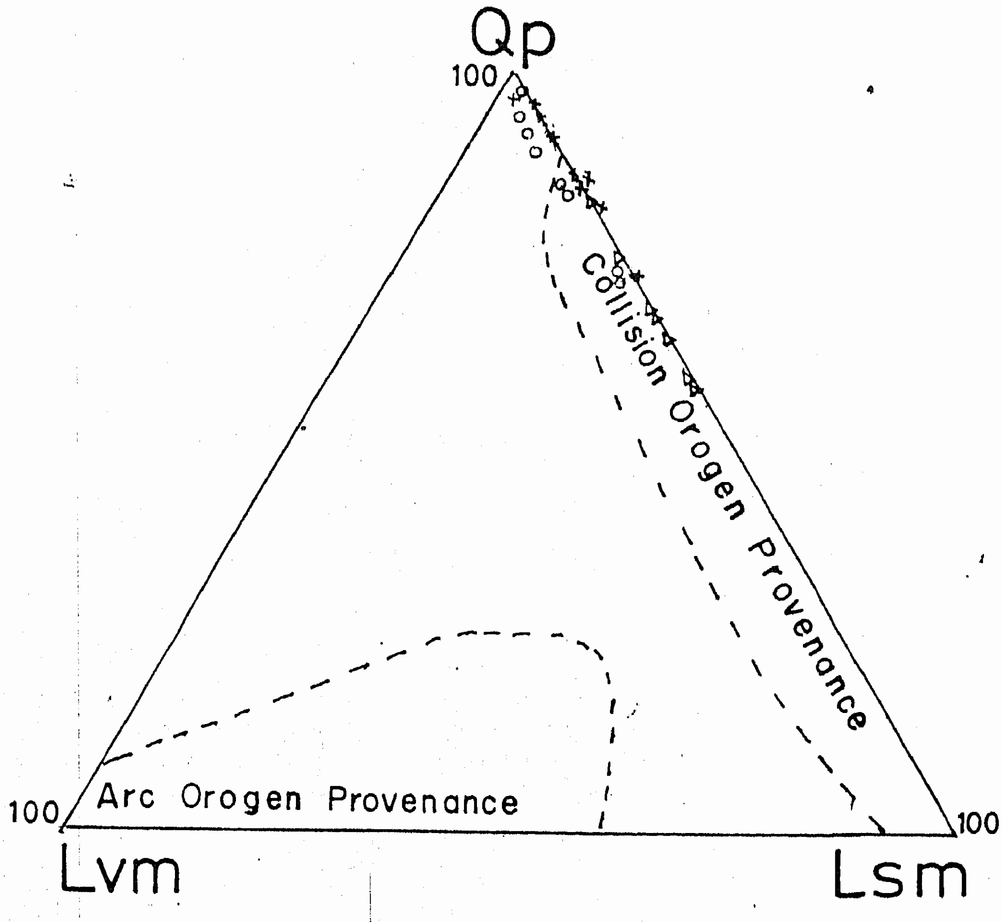

Fig. 24 Triangular QpLvmLsm plot of modal analysis for the sandstones of the Murree Formation. The provenance fields are after (Dickinson and Suczek 1979).

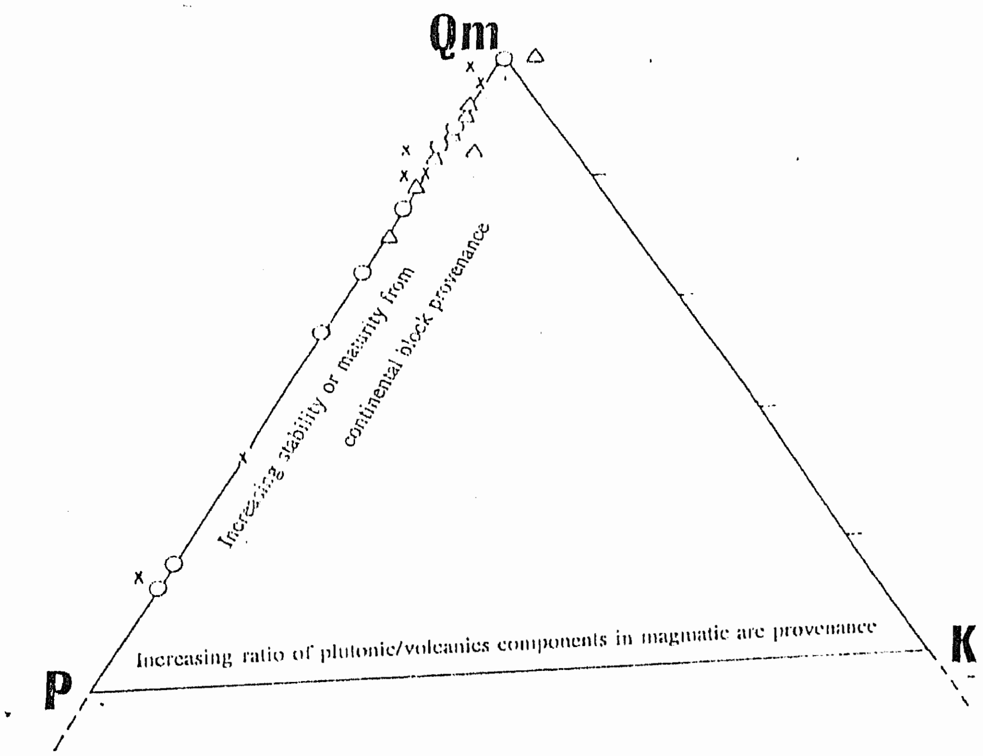

Fig. 25 Triangular QmPK plot showing mean proportions of monocrystalline mineral grains for sandstones of the Murree Formation derived from different provenance (after Dickinson and Suczek, 1979).

4.3 RESULTS

Percentages of the major components in the analyzed samples are given in Tabs. 4.1, 4.2 and 4.3. Tabs 4.5, 4.6, 4.7 and 4.8 show the recalculated percentage for the end member components QFL, QmFLt, QPLvmLsm and Qmpk. These methods of dividing the components into ternary divisions was used by Dickinson and Suczek, (1979), Dickinson et al., (1983) and Ingersoll and Suczeck, (1979). Each ternary divisions has its own specific characteristics e.g., the QFL diagram indicates maturity and grain stability which are largely the result of weathering, source, source relief and transport mechanism (Fig. 22). The QmFLt diagram indicates provenance and the grain size of the source material (Fig. 23). The QPLvmLsm and QmPK diagram plots only partial grain populations but reveal the character of poly-and monocrystalline components of the frame work respectively (Figs. 24 and 25). In QmPK plot the samples of three different sections plot towards the Qm end suggesting increasing maturity or stability of the continental block provenance (Fig. 25). Generalized tectonic provenance fields are given in diagrams QFL and QpLvmLsm (Figs. 22 and 24).

Majority of the samples fall in the domain of the recycled orogen provenance on both QFL and QmFLt ternary diagrams. The recycled orogen provenance field has been further subdivided into subduction complex, collision orogen and foreland uplift terrain by Dickinson and Suczek (1979). Majority of our data on the

QpLvmLsm diagram falls in the domain of collision orogen provenance.

On the QpLvmLsm diagram all the samples from the type section fall in the collision orogen provenance field, five samples from the Ghorzai section and four samples from the Pathan Algad section falls out of the range of the collision orogen provenance field as well as from the arc orogen provenance field and lie near the QP end corner. Therefore ternary diagrams suggest that the sandstone of the Murree Formation is derived from recycled orogen source areas either from collision orogen or foreland uplift sources or combination of both.

The basal conglomerates at the stratotype consist of dominantly limestone clasts, reworked from the underlying Eocene Formation.

4.4 DISCUSSION

Plots on the discriminatory diagrams suggest that the sandstone of the Murree Formation is composed of material derived from the orogenic belts to their north (Abbasi & Friend, 1989). Majority of the samples suggest recycled orogen provenance. Within this provenance field most of the samples fall in the domain of collision orogen provenance.

Abundant clear, inclusionless monocrystalline quartz in the sandstones of the Murree Formation may suggest that these were derived from the basement granitic rocks of the Indian Plate which got exposed at the surface due to subduction of the Indian Plate which ultimately resulted in uplifting and exposure to erosion. Stretched quartz crystal within some grains and quartz-mica tectonite, quartz-mica feldspar-tectonite and polycrystalline quartz suggest their derivation from metamorphic rocks such as schists and gneisses (Blatt, 1982) possibly from the Indian Plate cover sequence.

Generally among the feldspars, plagioclase is preferentially effected by weathering, still the plagioclase in the sandstones of the Murree Formation are abundant compared to the alkali feldspars. Muscovite is more abundant than biotite. As biotite is more prone to weathering its scarcity can be attributed to its alteration to other minerals like chlorite. Abundant muscovite, plagioclase and heavy minerals like epidote and garnet in the sandstone of the Murree Formation are combinally suggestive of a metamorphic source.

The chert grains may similarly have been derived from the older Indian Plate cover sequence. At least some of it may have been derived by erosion of the underlying Eocene strata (Kohat & Chorgali Formations) which contain abundant chert lenses and nodules.

It is, therefore, concluded that the major contributors to the strata of the Murree Formation were the granitoid rocks and the low to medium grade metamorphic rocks exposed on the northern margin of the Indian Plate.

The Murree Formation in Hazara-Kashmir syntaxis in northern Pakistan was deposited in late Paleocene to Early Eocene time. At that time Kohistan Island arc and Ladakh area which consists of ultrabasic to acidic magma were contributing to the Murree Formation. During Miocene the Tethyan oceanic crest had almost subducted beneath the Kohistan and Ladakh Island arc along the MMT (Bossart & Ottiger, 1989). This subduction resulted in the exposure of ophiolites and other low to medium grade metamorphic rocks (e.g., the mafic to ultramafic rocks along MMT and also metamorphic rocks south of it). Bossart and Ottiger, (1989) have suggested these rocks as source of the Murree Formation in older northernmost exposures. In contrast the Murree Formation in Kohat-Potwar area is Miocene in age (Shah, 1977; Tahirkheli, 1982). At that time Indian Plate was subducting beneath Kohistan Island arc and low to medium grade metamorphic rocks of the northern part of the Indian Plate were most likely acting as source for the Murree Formation in the Kohat-Potwar area.

Geochemical analysis of the garnet grains from the Murree Formation by Bajwa et al., (1987) when plotted on the Mn-Fe-Mg ternary diagram fall into high almandine-high spessartite zone with up to 95% Fe, 42% Mn, and 19% Mg. They further suggested that lack of pyrope in the Murree Formation may suggest that the erosion level in the source area at the Murree time was not so deep to touch the pyrope bearing deep seated high grade schist. According to them the sediments of the Murree Formation were derived from low grade schists and phyllites of the north and north-eastern part of the Indian Plate.

Recently Abbasi and Khan (1990) analyzed garnet and amphibole of the molasse succession in Kohat area and compared it with the data of these minerals available from the Himalayan orogenic source belt. They observed that majority of the garnet is almandine in composition with minor grossuler, spessertine and pyrope components. They observed that the garnet of the Rawalpindi Group in Kohat area is similar in composition to the garnet described by Bajwa et al.(1987), and is almandine in composition. This variety of garnet is similar to the one reported from crystalline Indian-plate basement rocks in Hazara, Swat and Besham area (Treloar et al., 1989a,b; Williams, 1989). The garnet in that area show wide range in metamorphic grades (garnet, staurolite, kyanite, silliminite). Abbasi and khan (1990) further described that few of the pyrope-grossuler rich garnet in the Murree Formation are similar in composition to those of Kamila Amphibolite of the Kohistan Arc sequence in North Pakistan. Indian-plate basement rocks does not contain comparable pyrope-grossuler rich garnet rather such garnets are reported from the Kohistan Arc sequence

(Jan, 1977; Jan and Howei, 1981) in the basal part of Kohistan sequence in Jijal Complex and Kamila Amphibolite. They concluded that the deep-seated high grade basement rock of the Indian Plate which were exposed before the deposition of the molasse succession in the Kohat area are responsible for contributing garnet to the Murree Formation. Nevertheless there could have been a minor contribution from the Kohistan Sequence, but the basal part of the Kohistan sequence started contributing garnet during the deposition of Indus Conglomerate Formation of Ahmad (1989) or Dhok Pathan Formation of Shah (1977).

Previously it was believed that the source of the high iron content of the Murree Formation was the Precambrian iron bearing Dharwar & Cuddaphah rocks of the Indian Shield (Wadia, 1931), but the hematite present in the Murree Formation is dominantly very fine-grained and appears diagenetic, with few detrital grains of hematite/magnetite. Thus the high iron content of the Murree Formation could not be considered a definite indicator of a southern source for the Murree Formation.

CHAPTER 5

5.1 SUMMARY AND CONCLUSIONS

The Murree Formation represents the early molasse sediments of the Himalayan foreland basin, which are characterized by the southward migrating depositional basin in response to the deformation of the orogenic belt. These rocks are limited in the north by the Main Boundary Thrust.

The Murree Formation consists of several lithofacies such as facies Gmt, Stp, Shl, Sr, Fl, and facies Fc. The Facies Gmt is interpreted as channel floor lag on the river beds; facies Stp is the principal facies of the lower to middle part of the point bars; facies Shl and facies Sr are generally found on the middle to upper part of the point bars; facies Fl resulted from the floods and is interpreted as levee or crevasse splays and facies Fc is the flood plain deposits which resulted as a fallout from suspension after the flood subsidence.

These facies show different associations at different localities. Facies Gmt mostly makes the base of sand-bodies. However, it also interchanges with facies Stp within the sand-bodies.

Facies Stp is the most common of all the facies. In several instances this facies makes the base of the sand-bodies. This facies either overlies facies Gmt or makes the basal part of the sand-bodies. Facies Shl which generally overlies facies Stp mostly lies in the middle or upper portions of the sand-bodies.

Facies Sr, where present, overlies facies Shl in the upper portions of the sand-bodies, as seen in sand-body SB2 at Pathan Algad. Facies Fl overlies the sand-bodies and act as transitional facies to facies Fc. Facies Fc is the uppermost facies of a fining-upward sequence. It either gradationally overlies the sequence via facies Fl or sharply overlies any of the other described facies in a sand-body.

The Murree Formation in the northern Kohat and in Potwar is more thicker than in southern Kohat at Pathan Algad. Major sand-bodies lie towards the base both at stratotype and at Pathan Algad. The same river could not have flowed at the same time in two widely apart east-west parallel locations specially when flow was generally from north to south. This suggests that either there was a considerable time gap between the strata of the Murree Formation at these localities or alternatively they were deposited by different streams or some combination of both. The basal strata at stratotype which appears to represent the initial river path could, therefore, be older than the basal part of the exposure at Pathan Algad.

The Pathan Algad area on the other hand possibly was on the margin of the Murree river system and, therefore, river flowed here occasionally only for a shortwhile and avulsed again towards east. Ghorzai area experienced repeated river passage and repeatedly was acting as flood plain area of the Murree river, consequently, developing cyclic sand-clay units.

The fining-upward sequences and the pattern of the lithofacies association suggests a meandering river. During deposition of the basal sandstone unit at stratotype subsidence rate was low, but the subsidence rate became higher in the upper portions of the section where thick clay facies predominate.

In provenance studies majority of the samples fall in the domain of the recycled orogen provenance on both the QFL and QmFLt ternary diagrams. The recycled orogen provenance field has been further subdivided into subduction complex, collision orogen and foreland uplift terrain by Dickinson and Suczek (1979). Majority of the samples on the QpLvmLsm diagram falls in the domain of collision orogen provenance. Therefore, ternary diagrams suggest that the sandstone of the Murree Formation was derived from recycled orogen source areas either from collision orogen or foreland uplift sources or combination of both.

The age of the Murree Formation has been established as Miocene (Shah, 1977; Tahirkheli, 1982). During Miocene the Tethys had almost subducted beneath the Kohistan and Ladakh Island arc along the MMT (Bossart & Ottiger, 1989). This subduction resulted in the exposure of ophiolites and other low to medium grade metamorphic rocks (e.g., the mafic to ultramafic rocks along MMT and also metamorphic rocks south of it). These rocks are inferred to be the ultimate source of the Murree Formation (Bossart & Ottiger, 1989).

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